ENVIRONMENTAL STUDIES FOR SUSTAINABLE AQUACULTURE (ESSA): 2004 SYMPOSIUM REPORT

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ABSTRACT

Hargrave, B.T. (Editor). 2004. Environmental Studies for Sustainable Aquaculture (ESSA): 2004 Symposium. Can. Tech. Rep. Fish. Aquat. Sci. 2542: *vi* + 81 p.

This report presents a project outline, completion report, extended abstracts from oral presentations and reviewer's comments arising from a symposium held at the completion of a three year (2000-2003) study (Environmental Studies for Sustainable Aquaculture) (ESSA) conducted by the Department of Fisheries and Oceans. Participants from federal and provincial government departments, the salmon aquaculture industry, universities and the general public met from 27 to 29 January, 2004 at Bedford Institute of Oceanography, Dartmouth. Presentations summarized research related to assessing potential far field effects of salmon aquaculture. Study sites were located in three areas (Bay d'Espoir (Newfoundland), Letang Inlet (New Brunswick) and south-central British Columbia (Broughton Archipelago)) where salmon aquaculture is concentrated in Canada. Physical circulation models describing the distribution of dissolved oxygen, nutrients and particulate matter provided a framework for considering chemical and biological variables in water and sediments that might be used as tracers for dispersion of dissolved and particulate wastes from farm sites. The observations were related to habitat management questions that require predictions and advice for monitoring of far field environmental effects of salmon aquaculture. An over-view and summary of research results from science and management perspectives are included.

RÉSUMÉ

Hargrave, B.T.(Editor). 2004 Environmental Studies for Sustainable Aquaculture (ESSA): 2004 Symposium. Rapp. tech. can. sci. halieut. aquat. 2542: *vi* + 81 p.

Le présent rapport contient une description sommaire de projet, le rapport d'achèvement de celui-ci et des résumés étoffés des présentations orales et des commentaires des examinateurs issus d'un symposium tenu à la fin d'une étude triennale (2000-2003) - s'inscrivant dans les Études environnementales pour une aquaculture durable - réalisée par le ministère des Pêches et des Océans. Les participants, comprenant des représentants du gouvernement fédéral et de gouvernements provinciaux, de l'industrie de l'aquaculture du saumon, des universités et du grand public, se sont réunis du 27 au 29 janvier 2004 à l'Institut océanographique de Bedford, à Dartmouth. Les présentations résumaient les recherches en matière d'évaluation des effets de champ lointain que peut avoir l'aquaculture du saumon. L'étude s'est déroulée en trois endroits du Canada où est pratiquée de manière concentrée une aquaculture du saumon, soit la baie d'Espoir (Terre-Neuve), le bras Letang (Nouveau-Brunswick) et le centre-sud de la Colombie-Britannique (archipel de Broughton). Des modèles de circulation physique décrivant la répartition des matières nutritives, des particules et de l'oxygène dissous ont permis d'examiner les variables chimiques et biologiques de l'eau et des sédiments qui peuvent parfois servir de traceurs de la dispersion des déchets dissous et particulaires

provenant des exploitations aquacoles. Les observations ont été appliquées aux aspects de la gestion de l'habitat qui nécessitent des prévisions et des conseils quant à la surveillance des effets environnementaux de champ lointain que peut avoir l'aquaculture du saumon. Sont également présentés un survol et un résumé des résultats des recherches du point de vue des sciences et de la gestion.

INTRODUCTION

The three-year project "Environmental Studies for Sustainable Aquaculture" (ESSA) was initiated in April 2000, funded by the Environmental Sciences Strategic Research Fund (ESSRF) within the Department of Fisheries and Oceans (DFO). The multi-disciplinary study involving DFO staff from three regions (Newfoundland (NF), Maritimes and British Columbia) focused on observations, methods development and modelling in Bay d'Espoir (NF), the Western Isles Region (Letang inlet) (New Brunswick) and in the Broughton Archipelago (British Columbia). Two interim workshops were held during the three-year study (Hargrave and Phillips 2001; Hargrave 2002a) to bring together all project participants, members of the steering committee and invited external reviewers. The meetings served to document progress in modelling, development and application of new methods that might be applied to detect gradients of environmental changes with increasing distance away from salmon farms, to refine objectives with respect to Habitat Management issues and to establish linkages with other relevant Strategic Science projects within DFO. This report summarizes the results of the final meeting of ESSA project participants in a wrap-up Symposium held at the Bedford Institute of Oceanography, 27-29 January, 2004. All members of the project, representatives of the salmon aquaculture industry and the New Brunswick provincial government departments responsible for management regulation of aquaculture attended the meeting and gave oral presentations. Abstracts of the presentations and comments by DFO management and an external reviewer submitted following the meeting are included.

ESSA PROJECT OBJECTIVES

Research during the ESSA project was conducted to contribute to the development of an effective Fisheries and Oceans management strategy for salmonid aquaculture in coastal marine waters of Canada. There were four main questions (objectives):

1. How can assimilative capacity of coastal waters be determined for wastes produced by marine finfish aquaculture?
2. What measurements can be made to document changing patterns and rates of sedimentation?
3. How can material released from aquaculture sites be tracked within a coastal system?
4. How can environmental observations/models be used by habitat managers to assist with recommendations as to the suitability of new farm lease applications and to mitigate potential environmental effects such that a Harmful Alteration, Disruption or Destruction (HADD) of fish habitat does not occur?

As the project developed these broad questions were focused to direct specific research activities carried out in three locations. Due to limits in resources not all research activities were carried out in all regions. For example assimilative capacity was not determined for the Broughton Archipelago where research activities primarily targeted questions 2 and 3.

1. Research was conducted to determine the assimilative capacity in three coastal regions (Bay d'Espoir, Letang inlet, and the Broughton Archipelago) where salmon aquaculture is concentrated in Canada. The aim was to compare cumulative and area-wide impacts of multi-source nutrient and organic matter loading in the three hydrographically different coastal inlet systems using broad-scale surveys and site-intensive studies.
2. Processes affecting particulate matter dispersion and sedimentation were observed and modelled to determine factors controlling the fate of fine-grained sediments in selected study sites.
3. Existing circulation and tidal models were used to predict water residence time and mixing characteristics, to make mass balance calculations and to predict suspended particulate matter, dissolved oxygen and nutrient concentrations.
4. Research results were synthesized and summarized in the form of models and decision tools that could be used by habitat managers to assist with management decisions concerning new site license applications and to determine optimum stocking densities (holding capacity) at existing leases.

PROJECT COMPLETION REPORT

DFO REGIONS: Maritimes, Newfoundland, Pacific
ESSRF PROJECT ID: 2021
DURATION: 3 YEARS (2000-2003)
TOTAL BUDGET: $728,000

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PROJECT DESCRIPTION

Research during the Environmental Studies for Sustainable Aquaculture (ESSA) project was designed to contribute to the development of an effective Fisheries and Oceans (DFO) management strategy for sustainable development of salmonid aquaculture in coastal marine waters in Canada. Broad-scale surveys and site-intensive studies in three coastal regions of Newfoundland, New Brunswick and British Columbia were carried out to develop methods that might be used for determining cumulative and area-wide impacts of multi-source nutrient and organic matter loading. Mass balance measurements and dispersion models of organic carbon, dissolved nutrient loading, oxygen consumption, particle transport and sedimentation

were used to evaluate potential far field environmental effects (not across all 3 regions). Results allow the environmental effects of finfish aquaculture to be evaluated within the context of the Fisheries Act to prevent conditions leading to a potential Harmful Alteration, Disruption or Destruction (HADD) and provide a framework for development within the context of integrated coastal management under the Oceans Act. Data and models produced from the project are of direct benefit to the industry through provision of advice on optimal siting criteria to minimize negative environmental effects and in providing information on the scale of inlet-wide effects for implementing effective Bay Management strategies.

Field observations and modelling studies were undertaken in Bay d'Espoir (Newfoundland), Western Isles region of the Bay of Fundy (New Brunswick) and the Broughton Archipelago (British Columbia) to develop and apply methods to quantify far field environmental effects of marine finfish aquaculture. The ESSA project, funded by the DFO Environmental Strategic Science Research Fund (ESSRF), was initiated in April 2000 and ended in March 2003.

The project had four primary goals posed as questions to be addressed in each DFO region as available resources allowed:

1. How can assimilative capacity be determined for wastes produced by marine finfish aquaculture?
2. What measurements can be made to document changing patterns and rates of sedimentation?
3. How can material released from aquaculture sites be tracked within a coastal system?
4. How can these environmental objectives be used by habitat managers to mitigate potential environmental effects such that a HADD of fish habitat does not occur?

ACCOMPLISHMENTS BY PROJECT OBJECTIVES

Question 1: How can assimilative capacity be determined for wastes produced by marine finfish aquaculture?

Water mass transport and mixing ultimately determine scales, pathways and rates of dispersion of dissolved and particulate matter released from point sources in any coastal area. The ability for assimilation of added organic matter by remineralization, burial and loss through physical exchange will therefore be determined by dilution resulting from water mixing and advection. During the ESSA project numerical circulation models were developed and used to determine inshore-offshore water exchanges and to track particles released from specific locations over time.

Horizontal mixing scales at different ESSA study sites were determined by application of geostrophic (mass balance) and finite element (FEM) tidal models to describe large-scale water properties and inlet-wide circulation (Fundy Isles region, southwest New Brunswick)(SWNB). The 3D FEM tidal model developed for the Bay of Fundy was modified during the ESSA project to allow for wetting and drying of intertidal areas - an important environmental feature in the macrotidal areas. Wind

forcing and effects of freshwater input are in the model formulations but have not been tested in the ESSA study region within SWNB (Greenberg et al. 2002). A web-based version of a larger coarse resolution model with seasonally modified wind speed and direction as input variables can be applied to roughly estimate potential trajectories of buoyant particles dispersed from farm sites in SWNB.

For the Broughton area two types of models are under development, a frequency domain, finite element model (Walter 1986) to simulate the depth-averaged tidal currents, and a finite volume/finite difference 3D circulation model – ELCIRC (Zhang and Baptista, 2004). ELCIRC can be forced with any combination of tides, winds, river runoff, and surface heating, and in its present application it has been initialized with salinity and temperature fields that were constructed from historical observations. In the models of the Broughton area, the 8 largest tidal constituents were used as they account for 85% of the tidal variance. This modelling work was funded through ACRDP in support of the ESSA project.

Boundary forcing in the SWMB model is by the principal semi-diurnal lunar (M2) tide, which generally gives good representation of the mean tide. Application of the models has shown that farms located in areas with long water residence times (low flushing rates) may retain particulate matter. Reduced dissolved oxygen in water within cages downstream and in sediments under net-pens has been observed at certain times in some locations in both SWNB and the Broughton area. The large-scale water property variations at the net pen sites in the Broughton Archipelago are controlled by the oceanography of Queen Charlotte Strait and the adjacent inland high-runoff fjords (Stucchi et al. 2002).

In some locations (SWNB) particulate matter and dissolved nutrients released from cages (as excretory products, feces and uneaten food pellets) were detected in the water column and sediments >500 m from farm sites. Dissolved nutrient levels are generally elevated throughout SWNB reflecting the eutrophic nature of the coastal water in the outer parts of the Bay of Fundy influenced by river discharge (Bugden et al. 2001). However, "hot spots" of higher nutrient concentrations above background levels were found in Back Bay and Black's Harbour. This shows that multiple sources of nutrients can combine to create widespread cumulative enrichment beyond that attributable to a single source. There was also evidence of increased levels of organic matter, zinc and copper in sediment near active farms and a fallowed lease site in SWNB and BC (Yeats 2002, Yeats et al. 2004).

The distances for dispersion of soluble substances such as nutrients and particulate matter were consistent with predicted model trajectories for neutrally bouyant particles 'released' in model runs at hourly intervals over 12 hours tracked over the following two to three tidal cycles (SWNB). Observations supported model output showing that soluble material released from farms in SWNB can be transported considerable distances depending current speed and direction over this time scale. Particulate matter tends to be transported shorter distances (generally <500 m) and is deposited in bottom sediments in areas of low current velocity. Resuspension events may cause post-depositional movement of sediment. This is most common in shallow water areas where fine-grain sediments predominate, such as inlets within SWNB.

Increases in dissolved inorganic nitrogen may stimulate harmful phytoplankton blooms potentially toxic to both salmon and wild species. For one region (SWNB) there was sufficient time series data to examine long-term trends in plankton biomass in areas close to and remote from farms sites (Page et al. 2001, 2002). Spatial sampling at four inshore-offshore stations showed inter-annual variations in the timing of peak cell abundances of dinoflagellates and diatoms with differences between regions. The number of species varied seasonally and was different between inshore and offshore sites. The spring bloom often occurs earlier in deeper offshore waters in SWNB and the magnitude (increase in cell numbers) is usually greater than in shallower inshore areas. No direct effects of proximity to salmon farms could be detected from these time series observations of inshore-offshore gradients that showed large inter-annual variations.

Since higher turbidity may limit light availability and primary production by phytoplankton (Harrison and Perry 2001), it is difficult to attribute differences in phytoplankton biomass and species composition in inshore areas specifically to the presence of salmon aquaculture. Similarly, high respiratory demand from particulate and dissolved organic carbon in both inshore and offshore areas in SWNB suggest the possible influence of local river input, sediment resuspension and the St. John River plume as it extends south and west into offshore areas of the Quoddy region (Kepkay et al. 2002). Smith et al. (2002) compared $^{137}Cs/^{210}Pb$ sediment inventory ratios in cores collected throughout the Western Bay of Fundy to show that sediment deposition in Letang Inlets is dominated by inputs from local sources. The Quoddy region, on the other hand, appears to be a sink for particles generated over a much wider area, including cliff erosion and suspended matter from the St. John River. The influence of river-derived particulate matter may be observable in sediments as far south as Grand Manan Island. If spatial effects of aquaculture development on carbon cycling in SWNB are to be quantified, the magnitude of near versus offshore resuspension and input from rivers needs to be defined in relation to currents that move material within and between inshore and offshore areas.

As an example of how ecological measurements may be used to determine optimal holding capacity and long-term sustainability for management of salmon development in any coastal area, model calculations were carried out for SWNB where data are most complete (Fisheries and Oceans 2003a). Mass balance calculations were based on Approved Production Limits (APLs) from data provided by the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA). Estimates of cultured fish biomass, scaled by volume and area, were made for oceanographic/hydographic areas (Coastal Management Regions) (CMRs) proposed by DFO in 1998 using water mass mixing and residence time characteristics. The CMRs incorporate the 22 smaller Bay Management Areas currently used by NBDAFA. Estimates of carbon, nitrogen and phosphorus stored in fish tissue and produced as waste from fish feces, urine and excess feed were made using physiological parameters for one and two year old salmon. Oxygen used in respiration and for decomposition of feces and waste feed and release of soluble nutrient and particulate wastes was compared with other anthropogenic and natural sources of biological oxygen demand (BOD) and nutrient fluxes. Estimates of fish biomass,

based on APLs were used to calculate salmon respiration, and release of soluble and particulate waste products to compare with natural fluxes on a per area basis in each CMR.

Observations and a respiration-advection model described in Fisheries and Oceans (2003a) used to assess optimum holding capacity showed that dissolved oxygen concentrations <6 mg l^{-1} should be avoided for ecosystem protection, sustained production and health of caged salmon. Using a proposed 'rule-of-thumb' that fluxes of oxygen, carbon and nitrogen through salmon should not exceed 20% of total fluxes for these elements from all sources in a CMR, the mass balance calculations showed that reductions in APLs are required in three inlets (Lime Kiln Bay, Bliss Harbour and Back Bay) in the Letang area of SWNB. Fluxes due to lower numbers of salmon currently grown in other CMRs do not exceed the proposed 20% threshold. Reduction of numbers of salmon in these most affected areas would mitigate negative environmental interactions and changes, and reduce risks associated losses of production and revenue by the industry due to poor growth performance.

Modelling of the dissolved oxygen variations in the Broughton has not as yet been undertaken, but naturally occurring seasonal variations dissolved oxygen are well below (~4 mg l^{-1}) (Stucchi et al. 2002) the 6 mg l^{-1} level mentioned earlier. Consequently, any additional demand imposed by aquaculture operations will exacerbate the naturally occurring sub-optimal dissolved oxygen conditions in the late summer and fall.

Question 2: What measurements can be made to document changing patterns and rates of sedimentation?

Assimilation of added organic matter will to some degree be influenced by local rates of addition. If loading is sufficiently low and natural rates of oxygen supply are maintained, local BOD should not create oxygen deficiencies that would stress cultured salmon or other species (i.e. oxygen concentrations will be >6 mg l^{-1}) (Fisheries and Oceans 2003a). However, if advection and particulate matter dispersion rates are low, as in areas of reduced currents, increased organic matter sedimentation from settled particulate waste products and natural plankton blooms can reduce oxygen concentrations in the water column and hypoxic or anoxic conditions may develop in surface sediments. This is potentially most likely to occur in areas where flushing is reduced and fine particles accumulate in sediments.

Increased organic matter sedimentation was measured under and close to cages in areas where currents were low (mean tidal values <5 cm s^{-1}) in all three ESSA study areas, but the spatial extent of increased sedimentation and benthic enrichment away from net-pens was variable between locations. Several factors such as local circulation, bathymetry, resuspension and farm husbandry practices accounted for variable sedimentation rates in different locations. Relationships between redox potentials and total free sulfides in sediments observed in SWNB were compared with similar measurements in Bay d'Espoir and the Broughton Archipelago. The general log-linear relationship between these variables in hypoxic and anoxic sediments was similar in all three ESSA study sites where fine-grained sediments occurred.

Seasonality in sediment geochemical variables indicative of organic enrichment of soft, depositional areas was studied under net-pens and at distant reference sites in Lime Kiln Bay (SWNB) during the ESSA project (Wildish et al. 2002, 2003a). Measurements of surface sediment organic matter, redox potentials and total sulfides form the basis of a late summer/early fall environmental monitoring program conducted annually at all farms sites licensed within the Province of New Brunswick (Wildish et al. 2001a). Redox potentials in aerobic, oxic sediments showed a seasonal sine wave pattern with lowest values (more reducing sediment) in late summer during periods of maximum temperature. With organic enrichment when anaerobic conditions reach the sediment-water interface, redox potentials are inversely related to total sulfides. No seasonality was observed in total sulfides in surface sediments as was expected based on studies in other eutrophic coastal areas where bacterial sulfate reduction was maximum (seasonal?) at maximum temperatures in late summer. As shown elsewhere, sediment profile imaging (SPI) appears to be a useful tool for rapid, semi-quantitative assessment of organic enrichment effects on sediment geochemical variables and benthic faunal communities in shallow environments (Wildish et al. 2001b, 2003a, 2004). Visible changes in sediment texture and colour occur at the sediment-water interface along an organic enrichment gradient as oxic-hypoxic-anoxic conditions are altered and reducing (sulfide-rich) sediment layers develop closer to the surface.

The above trends apply to those environments characterized by soft-sediments where traditional sampling methods are employed to detect organic enrichment. However, similar detection methods have not been developed for rocky boulder substrates which make up a large proportion of seafloor characteristics influenced by finfish operations within the BC environment. Thus, the results for the Broughton Archipelago are based largely on those areas typified by soft-sediments. Where possible both macrofaunal and meiofaunal samples were collected using a Van Veen grab, and geochemical parameters (sulphide/redox) were collected using a gravity core. Preliminary analysis of these data reveals spatial trend in geochemical and faunal characteristics relative to fishfarm locations.

Question 3: How can material released from aquaculture sites be tracked within a coastal system?

A major achievement during the ESSA project was the demonstration that multibeam (EM3000) methods to map sediment backscatter intensity could be used to differentiate depositional areas of soft sediment in all three study areas (Hughes-Clarke 2001, Hughes-Clarke et al. 2002, Sutherland 2001b, Tlusty et al. 2001). Multibeam maps were prepared for sites of varying size in all three ESSA study areas. QTCView (a bottom type classification system) surveys were also completed in Bay

d'Espoir and at one site in the Broughton Archipelago. Data from some of these studies has been analyzed to show that acoustic information can be used to differentiate erosional and depositional bottom types and to identify areas of gas-filled, fine-grained sediments (Tlusty et al. 2001; Wildish et al. 2004). This approach allows targeted sampling for fine-grained, organically rich sediments within any

system where finfish aquaculture is developed. This aspect is extremely important in areas tidal currents and uneven bathymetry caused depositional footprints to be irregularly shaped or to be displaced "downstream" relative to the fishfarm location. Studies of particle aggregation and flocculation in the water column have shown that organically rich small particles suspended in the water column may become flocculated and transported to depositional areas where they accumulate on the bottom (Milligan et al. 2001), thus making these sites candidates for long-term environmental monitoring programs.

In addition to dissolved nutrients and organic matter, finfish farms may release soluble and particle-associated contaminants that are available for widespread dispersal by currents. Increased levels of copper (used to reduce biofouling on nets) and zinc (a metabolic additive to fish food pellets) were measured in sediments at variable distances away from farm sites in SWNB and BC (Yeats 2002, Sutherland et al. 2002). The observations support studies in other locations that have shown that these metals can be useful tracers for measuring far field dispersion of soluble and particulate material from salmon farms. Yeats et al. (2004) have shown that in order to define an elevated concentration of zinc or copper, a Lithium-normalization technique must be applied to the data set of interest. It must be emphasized that even the most elevated levels of zinc and copper measured in SWNB were well below the probable effects level guidelines for contaminants in marine sediments. However, anomalously high values of both trace metals were correlated with increased sedimentary organic matter indicating their usefulness for tracing the horizontal extent of organic enrichment.

Research has been carried out to examine the occurrence and source of antibiotic resistance in aerobic bacteria in marine sediments in SWNB. Cantox Environmental Inc. (2001) summarized chemical use in aquaculture in Atlantic Canadian in 1998-99 and estimated that 230 g of OTC was used ton^{-1} of fish produced (equivalent to an application rate of 42 g of OTC 1000^{-1} fish). Veterinary records could be examined to verify or update the amounts prescribed and to show where OTC-medicated feed has been used more recently in SWNB, but it has not been possible to obtain this information. A new OTC resistance bioassay was applied to surface sediment samples collected under net-pens and distant from farms sites (Friars 2002, Friars and Armstrong 2002). A Gram negative, non-motile, coccobacillus (genus *Psychrobacter*) was present in samples showing antibiotic resistance (operationally defined as growth at OTC concentrations >25 $\mu g\ ml^{-1}$). An HPLC-MS method was used to measure traces of OTC in some samples. No measurable OTC residues or antibiotic resistance were detected in surface sediments from coastal areas in NB and NS considered as control sites where salmon aquaculture does not occur.

In coastal waters where eutrophication leads to increased supplies of dissolved nutrients, intertidal areas are often locations where enrichment effects may be observed as stimulation in macroalgal growth. Observations in several inlets in SWNB away from the direct discharges of nutrients (sewage treatment plants and industrial waste outfalls) showed higher levels of dissolved nitrogen compare to offshore areas, increased coverage (biomass) of intertidal sediment by macroalgae (*Enteromorpha* sp.and *Ulva* sp.) and decreased growth and gonad production in

intertidal soft-shell clam (*Mya arenaria*) populations (Auffrey et al. 2002). Intertidal areas may be ideal locations for long-term studies of cumulative far-field effects of nutrification.

Question 4: How can these environmental objectives be used by habitat managers to mitigate potential environmental effects such that a Harmful Alteration, Disruption or Destruction (HADD) of fish habitat does not occur?

A major objective of the ESSA project was to provide Habitat Management Division with advice useful for avoiding or mitigating potential environmental effects due to a HADD of fish habitat. A prototype PC-based decision support system for application in SWNB (Hargrave 2002b, Doucette and Hargrave 2002) was developed to illustrate how variables listed in licensing applications could be used to assess potential negative environmental factors and rank the suitability of a proposed site. Knowledge regarding habitat heterogeneity, sampling methodologies, and organic enrichment trends gained through the ESSA project have helped scientists provide ongoing advice to HEB on various applications including CEAA reviews, PSARC requests, etc. (Levings et al. 2002).

As an example of how ecological measurements may be used to determine optimal holding capacity and long-term sustainability for management of salmon development in any coastal area, model calculations was provided for SWNB (Fisheries and Oceans 2003a). Mass balance calculations were based on Approved Production Limits (APLs) from data provided by the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA). Estimates of cultured fish biomass, scaled by volume and area, were made for oceanographic/hydographic areas (Coastal Management Regions) (CMRs) proposed by DFO in 1998 using water mass mixing and residence time characteristics. The CMRs incorporate the 22 smaller Bay Management Areas currently used by NBDAFA. Estimates of carbon, nitrogen and phosphorus stored in fish tissue and produced as waste from fish feces, urine and excess feed were made using physiological parameters for one and two year old salmon. Oxygen used in respiration and for decomposition of feces and waste feed and release of soluble nutrient and particulate wastes was compared with other anthropogenic and natural sources of biological oxygen demand (BOD) and nutrient fluxes. Estimates of fish biomass, based on APLs were used to calculate salmon respiration, and release of soluble and particulate waste products to compare with natural fluxes on a per area basis in each CMR.

BENEFITS

The ESSA project examined current methods and models used to determine the scope and magnitude of far-field environmental effects and their implications for management of marine finfish aquaculture in three DFO regions (Newfoundland, Maritimes and Pacific). Issues such as reduced dissolved oxygen, enhancement of phytoplankton blooms, release of excess feed, faeces and excretory products, benthic organic enrichment, sediment accumulation and chemicals used in aquaculture and their potential toxicological effects were examined in various sub-projects. Project results were reported in numerous publications, both primary papers and technical

reports and were summarized to industry, provincial and federal government staff at annual workshops (ESSA: 2001, 2002, 2004), briefings, in a DFO state-of-knowledge report on aquaculture-environment interactions. Research results from the project were communicated to representatives of the finfish aquaculture industry, graduate students, scientists, government environmental managers and decision-makers with regulatory responsibilities. A computer-based decision support system was developed using results from the project to evaluate potentially negative near and far field environmental effects to aid in site selection to avoid locating new fish farms in areas where the a potential for creating a HADD may exist. The system is currently being used and evaluated as a management tool within DFO.

CLIENTS

Research results were presented orally at various workshops, seminars and scientific meetings between 2001 and 2003 (see Abstracts and Presentations section below). Salmon aquaculture industry representatives and others from various federal and provincial agencies (e.g. provincial departments of fisheries and aquaculture, and environment, Office of Sustainable Aquaculture, Environment Canada) involved with aquaculture development and regulation attended the annual workshops. Informal meetings were held with the industry in each region to present interim research results.

Results from the ESSA project were summarized in a comprehensive DFO State-of-Knowledge Report on far-field environmental effects of marine finfish aquaculture (Fisheries and Oceans Canada 2003b).

In early 2003 ESSA participants from the Maritimes Region were asked by the Directors of Science and Oceans Branches to prepare a Discussion Paper on the status of salmon aquaculture-environment interactions in SWNB. The aim was to determine if there was a scientific basis for determining sustainable holding capacity. Eight research scientists involved in the ESSA project contributed to the paper. The report submitted to the Maritimes Regional Director of Science was published as a DFO Technical Report (Fisheries and Oceans 2003a). Industry and provincial government staff (NBSGA, NB Departments of Environment and Fisheries and Aquaculture) were briefed on the findings.

Many ESSA project participants have submitted manuscripts for peer review and publication as chapters in special volume of The Handbook of Environmental Chemistry series (Springer-Verlag). The volume, *Environmental Effects of Marine Finfish Aquaculture* to be published in 2005, is intended for a broad audience concerned with sustainable aquaculture development including members of the aquaculture industry, environmental managers and decision-makers with regulatory responsibilities, scientists and graduate students.

DATA MANAGEMENT

Physical, chemical and biological data collected during the ESSA project is available in Access databases and Excel spreadsheet files from the three principal investigators.

Measurements of water column or sediment variables sensitive to movements of dissolved and particulate material in the three study areas are geo-referenced. The information will reside in working files managed by the PIs in each region (Newfound-Anderson; Maritimes-Hargrave; Pacific-Sutherland) until installed in a permanent database. Subsamples of some sediments remain unanalyzed and are archived (dry, preserved, or frozen at -18 C) for further analysis if required.

Work is currently underway within the Data Management Section, Marine Environmental Sciences Division, Maritimes Region, to prepare a comprehensive database of all ESSA primary data. Contact should be made with Pierre Clement (Maritimes Region) the regional data manager working on this project.

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ABSTRACTS AND PRESENTATIONS

2001

ESSA 2001 Annual Workshop- Jan 17-19, BIO
BC Technical Advisory Group Meeting- Jan 24, Naniamo, BC
BC Science Council Meeting- Feb 1, Naniamo, BC
Habitat Management National Working Group on Aquaculture- Jan 31, Halifax, NS
GOM Council Working Group on Environment-Aquaculture- March 9, Augusta, ME
NBSGA Science Committee - April 29, St. George, NB
PICES Workshop on Aquaculture-Environment Interactions- Oct 15, Hakodate, Japan
DFO National science Workshop, IOS- Nov 14, Sidney, BC

2002

Habitat Management National Working Group on Aquaculture- Jan 15, Halifax, NS
ESSA 2002 Annual Workshop and Joint Meeting with HMNWGA- Jan 16-18, BIO
DFO/BIO Branch Management Committee (DFO)- May 21, Dartmouth, NS
American Society of Limnology & Oceanography Annual Meeting (Aquaculture Environment Interactions)- June 13-16, Victoria, BC
Minister's Briefing - Aug 22, Ottawa, ON
Canada Center for Inland Waters (seminar)- Oct 6, Burlington, ON
MESD Division Review- Nov 14-15, Memramcook, NB

2003

Dalhousie University, Dept. of Oceanography seminar- Jan 31, Halifax, NS
Habitat Management Regional Workshop on Aquaculture Monitoring Methods- Feb 4, Gander, NL
MESD State-of-Knowledge Report (DFO Headquarters presentation)- Feb 21, Ottawa, ON
National Habitat Management Working Group on Aquaculture- Mar 4-6, Vancouver, BC
Environment Canada Working Group on Aquaculture- Mar 18-19, Halifax, NS
IOS Seminar Series- Mar 21, Sydney, BC
NBSGA Science Committee- Aug 6, St. George, NB
Aquaculture Association Conference- Oct 31, Victoria, BC
DFO National Science Workshop- Nov 19-21, St. John's, NL
BCARDC Farm Waste Management Workshop- Nov 25-26, Victoria, BC

2004

ESSA Symposium – 27-29 January, Bedford Institute of Oceanography, Dartmouth, NS

EXTENDED ABSTRACTS

(ordered alphabetically by first author)

Organic enrichment at cold water aquaculture sites – the case of coastal Newfoundland

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One of the principal objectives of the Environmental Studies for Sustainable Aquaculture (ESSA) Project was to evaluate tools and protocols for used by Habitat Managers to assess the potential environmental effects of finfish aquaculture. One such tool is the redox-sulfide (Eh-S) continuum developed for aquaculture sites in New Brunswick and Prince Edward Island. The empirical relationship between Eh and S is used to situate sites with regard to organic matter (OM) loading and to monitor shifts in benthic habitat quality using the known links to evolution of anoxia with excessive OM input. Measurements of Eh and S have been made in sediments at finfish and shellfish farms and at reference sites in coastal Newfoundland. There was a significant ($p<0.01$) relationship between these variables in the sediments examined. However, there was a great deal of unexplained variation and 70% of the observations fell below the Eh-S regression line derived from sediments collected around salmon aquaculture sites in New Brunswick and mussel farms in Prince Edward Island. In this presentation we explore potential causes of this variation and discuss how these may influence the application of this tool.

Sediments in Newfoundland coastal waters tend to be naturally rich in organic matter (OM), ranging from 1.5% to >30% weight loss on ignition (LOI) (median 8% LOI). In addition, they are seasonally cold (< 0°C) and in some cases always cold (-1.8 to <5°C). Temperature and both quantity and quality of OM in sediments have been shown to significantly influence the rate of sulfate reduction in coastal sediments. As well, mesophilic and psychrophillic sulfate reducers respond differently to temperature. Thus sediment composition, temperature and the nature of microbial populations may influence the formation of sulfides under such conditions.

Other factors that may influence sediment conditions must also be taken into consideration in the application of this relationship to farm management in coastal Newfoundland. Much of the Newfoundland coast is exposed to high energy conditions often with effective fetch exceeding 700 km. Wind, waves, storm surge and seasonal currents can resuspend deposited organic material and effectively scour seasonal depositional areas. Sediment focussing in steep sided fjords and inlets will also move deposited material away from farm sites. Seasonality of sediment conditions must therefore be considered in applying the Eh-sulfide relationship to these sites. Water column structure and movement will also influence the oxygen content of bottom waters. Inner basins of fjords may experience seasonal anoxia that

will significantly influence sediment water exchange processes. Such sediments may also be devoid of macrofauna and the lack of bioturbation will also influence sediment rate processes.

These observations suggest that application of the Eh-S relationship to Newfoundland coastal waters is a useful environmental assessment and management tool, but cannot be extrapolated directly from those data of other regions. Seasonality and water column conditions at the site need to be factored in to the sample plan and the data interpretation (as well as method of collection: grab vs coring method).

Microbial resistance to oxytetracycline in sediments from salmon aquaculture sites in the Western Isles region of the Bay of Fundy

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Introduction

From inception antibiotics have been used as a "cost-effective" means to mitigate microbial infections in the aquaculture industry. Antibiotics are administered to treat fish by various methods:

A. Feed additives;
- Consumption rates by sick fish
- Excess antibiotic laden feed into environment
- Efficiency of antibiotic absorption by gut
- Amount excreted in the feces

B. Antibiotic injection;
- Less-antibiotic used to treat all fish, thereby reducing environmental impacts
- Generally cost-averse

C. Antibiotic baths;
- Easier than injections and more effective than feeds
- Large environmental impact, since antibiotic laden water usually discharged into the environment.

Oxytetracycline (OTC) is the predominant antibiotic used in the Canadian aquaculture industry. OTC is bacteriostatic and interferes with protein synthesis by reversibly binding to the 30S ribosomal subunit, thereby blocking the binding of aminoacyl tRNA to mRNA/ribosome. OTC is a powerful chelating agent and the effectiveness can be reduced by high concentrations of multivalent metal ions as found in seawater.

TE (OTC) resistance gene determinants (>30) have been categorized into the following groups: proton-dependent efflux of TE's, ribosomal protection by cytoplasmic proteins, and enzymatic degradation of TE's (Bacteroides), and rRNA mutations (*H. pylori & P. acnes*)

Research Objectives

Our study had three main objectives:

A. Develop a new protocol for quantifying OTC resistance in an efficient manner
B. Test the hypothesis that there are any significant differences in OTC resistant microbes from aquaculture and control sites
C. To isolate and characterize any OTC resistant microorganisms

Methods

Sample Collection

Sample collection in Letang inlet at 11 aquaculture sites (1, 2, 3, 4, 5, 8, 13, 14, 18, 20, 24) was carried out at locations 0, 25, 50, 100 m parallel and perpendicular to the current, with 0 m being immediately under the fish cage. St. Ann's Bay (samples 147836 and 147839), Passamaquoddy Bay-Mascarene Shore (MS) and Limekiln Bay (LB) were control sites. Microbial analysis (total, viable, and OTC resistant counts) was determined at 72 hours, with viable and OTC resistant microbes being cultured on Muller Hinton (MH) media.

Minimum Inhibitory Concentrations (MIC)

MIC was determined as the lowest OTC (employing a 2-fold dilution series) resulting in inhibition of microbial growth. Positive evidence of growth was provided if optical density (OD) values of cells in MH media $\geq$0.25 at 625 nm. All experiments were performed in replicate (N= 4) and OD values were determined at 48 hours

OTC Resistance Determination

Microbial OTC resistance was assessed using a microtitre plate method at 0, 5, 10, 20, 40, 80, 160 μg mL^{-1}, with 200 μL aliquots samples placed in the wells. Plates were incubated in the dark at 22°C and shaken at 100 rpm with OD_{625nm} readings taken every 12 hours using a *SPECTRAmax Plus 384* spectrophotometer. Conversion of OD_{625nm} values to cell numbers was carried out using the regression equation: y = 3.4*X-0.12 (r^2=0.89). K_{max} values for each of the samples at the various OTC concentrations were determined from the growth curve data (K_{max}= ($\log_{10}$ X – $\log_{10}$ X_0)/$\log_{10}$ 2 x t).

16S rRNA ribotyping

OTC resistant isolates were purified on MH media supplemented with 25 μg mL^{-1} OTC. Genomic DNA was extracted using a salt extraction method (Alijanabi & Martinez 1997). PCR amplification was performed using *Ready To GoTM PCR Beads* with the following primers: forward sequence: 5′CC GGA TCC ACT CCT ACG GGA GGC AGC AG(AG) GGA, reverse sequence: 5′CC AAG CTT CGG GCC CGT CAA TT(CT) CTT TGA GTT T. PCR conditions: Initial denaturation (95°C, 5min), subsequent denaturations (95°C, 30 sec), annealing (59°C for 30 sec), elongation (72°C, 1 min), termination (35 cycles, held at 4°C)

Sequence Data Interpretation

Sequence data from forward and reverse reaction was aligned using Clustal X multiple sequence alignment program. Aligned partial 16S rRNA gene sequences were searched for the closest match using GeneBank. Using the homology search tool

Blast and the GenBank databank close phylogenetic relations of the unknown bacteria were determined. A phylogenetic tree was created using *Clustal X* with *B. subtilus* serving as the out-group to root the tree.

Results & Discussion

Microbial Characterization of the Sediment Samples
The total, viable and OTC resistant bacterial numbers g^{-1} dry sediment showed that there were significant differences numbers of OTC resistant bacteria in all samples analyzed. There was no significant difference for bacterial numbers g^{1} dry sediment for the total, viable, or OTC resistant bacterial along the parallel or perpendicular 100 meter transects. The percent frequency of OTC resistant bacteria to total bacteria in the sediment ranged from 0.001% to approximately 95%.

Extent of OTC Resistance
OTC resistance was measured in all sediment samples collected up to100 meters parallel to and perpendicular from the centre of the cages. MIC values were typically in the range of 80 µg OTC mL^{-1}. The K_{max} values (generations h^{-1}) were low in all samples from control areas where MIC values were 5 OTC µg ml^{-1}. Bacteria cultured from all experimental (farm) sites had higher K_{max} values and typically showed growth occurring at concentrations of OTC from 80 to 160 µg mL^{-1}.

Psychrobacter sp.
The predominant genus of bacteria growing in the presence of OTC was *Psychrobacter* sp. as determined by 16S rRNA sequencing and data interpretation using phylogenetic analysis. The microbes are of the gamma Proteobacteria family, Gram-negative, non-motile, halotolerant, and psychrophile. The genus has been identified in a number of human sources that are commonly isolated from cold environments (i.e. soil, sea-ice, skin and gills of fish). They are also associated with food spoilage and frequently resistant to irradiation which is often used in food preservation. *Psychrobacter* sp. are considered as extremophile.

Conclusions

OTC resistant bacteria were found in all sediment samples collected up to 100 meters parallel and perpendicular to 11 salmon aquaculture sites in different inlet systems in the Western isles region of the Bay of Fundy. This suggests that antibiotic resistant microbes occur over a broad area in this region of intensive salomon aquaculture. A rapid quantitative test for the detection of antibiotic resistant microbes was developed during our study which could be applied to determine the spatial extent of antibitoic resistance in regions where aquatic sediments are impacted by release of OTC into the environment. Molecular determination of the predominant isolates as *Psychrobacter* species growing in OTC-supplement media suggests that antibiotic resistant microbes may be associated with the food pellets. New research is required to determine if this is the source of resistant micro-organisms in the study area.

Chemicals to control sea lice infestations:
What we know about their effects on lobster

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The salmon aquaculture industry and the commercial lobster fishery coexist in southwest New Brunswick. Questions have arisen about the effects of pesticides and drugs, used to treat salmon against sea lice infestations, on lobsters. In Canada, only azamethiphos (trade name Salmosan®) and emamectin benzoate (trade name SLICE®) are currently being used to treat salmon for sea lice. The registration of Salmosan® expired in 2003 and apparently will not be renewed.

Azamethiphos is lethal (48 h LC50) to larval and adult lobsters at concentrations ranging from 1 to 3 % of the recommended treatment concentration (100µg L^{-1}). There is no significant difference in sensitivity to this compound among the first three larval stages, the first post-larval stage and adults. Azamethiphos is significantly more lethal to lobsters during the summer than at other times of the year. While water temperature may play a role in this response it is likely that the physiological stage (spawning or molting) of females is also important. Repeated 1-h exposures to azamethiphos (10 µg L^{-1}) have been shown to affect spawning in female lobsters.

Lobsters are not considered to be at risk of dying as a result of ingesting fish food medicated with emamectin benzoate (EB). The 7-day LC50 is approximately 60 times the normal treatment concentration (10 µg g^{-1} of fish food) used to achieve the recommended treatment dose (50 µg $kg^{-1}$of fish d^{-1}).

Exposure to EB has resulted in premature molting in certain life stages of lobsters. The probability that lobster may molt prematurely, as a result of ingestion of EB, is dependent on a multitude of factors including spawning status of females and molt status of males and females. In addition, work is ongoing to determine the likelihood that lobsters will eat feed pellets in the wild and whether repeated exposure to low doses of EB produce the same response(s) as single exposures.

The majority of this work has been conducted in the lab and field studies are lacking. The nature of the sublethal responses has not been fully investigated. Finally, the risk of identified hazards occurring in the wild has not been assessed.

A regression model using sediment chemistry for evaluating near-field effects associated with salmon aquaculture cage wastes

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Introduction

Currently there are very limited approaches for assessing the impacts of aquaculture on sediment with the exception of the environmental monitoring program (EMP), implemented by the Department of the Environment and Local Government (DELG), New Brunswick, Canada. EMP is based on sediment redox potential, sulfide concentrations, and video transects data for monitoring environmental effects of salmon aquaculture operations (DELG, 2000). The impacts are considered unacceptable when sediments become anoxic. There is a need for the development of more sensitive tools and methods for detecting environmental effects of aquaculture and for determining what constitutes acceptable and unacceptable impacts. Other sediment chemistry indicators of environmental effects would assist in assessing the sustainability of aquaculture operations.

There are very few studies describing sediment chemistry as it relates to the deposition of wastes from marine aquaculture. The sources of wastes at salmon aquaculture farms are excess feed, excretory products and chemicals used both in the treatment of diseases, and as disinfectants, antifouling agents and cleansers. Wastes generated by net-pen operations typically include organic matter and nutrients from faeces and uneaten feed pellets, as well as trace metals used in feed ingredients. At aquaculture sites, the composition of the sediments is altered by aquaculture waste. Understanding the changes in sediment chemistry associated with the discharged waste from aquaculture activity would assist in the prediction of impacts and in sustainable use of the marine environment. One approach is to use environmental tracers. A tracer is a signature or fingerprint related to the environmental response resulting from the accumulation of enriched organic waste from aquaculture operations around the net-pen. The tracers could be additives in feed, organic carbon, metals, benthic assemblages, ^{14}C, nutrients, medicinal treatments, etc. The objectives of this study are to: 1) quantify the impacts from the aquaculture operations using sediment metals, organic carbon and <63 μm particles, 2) select the proper factors for normalising the chemistry of sediments in and around the cage, and 3) develop a statistical model for predicting the environmental monitoring program conditions of anoxic, hypoxic, or normal as they relate to aquaculture activities.

Materials and Methods

Sediment samples were collected by divers from under the cages (0 m) and at 50 m from the cage edge at 14 salmon aquaculture cage sites in Passamaquoddy Bay, southwestern New Brunswick (Fig. 1). Sampling sites were anonymous in this report. The EMP ratings were assessed by diver, on-site, following the environmental monitoring program guidelines as defined by the Department of Environment and Local Government of New Brunswick, Canada (DELG, 2000). Sediment samples were transported to the Bedford Institute of Oceanography. Chemical analysis was conducted following the procedure of Chou *et al.* (2000). The principal components analysis (PCA) and regression analyses were carried out on the data using Systat 9 (SPSS Inc., 1999).

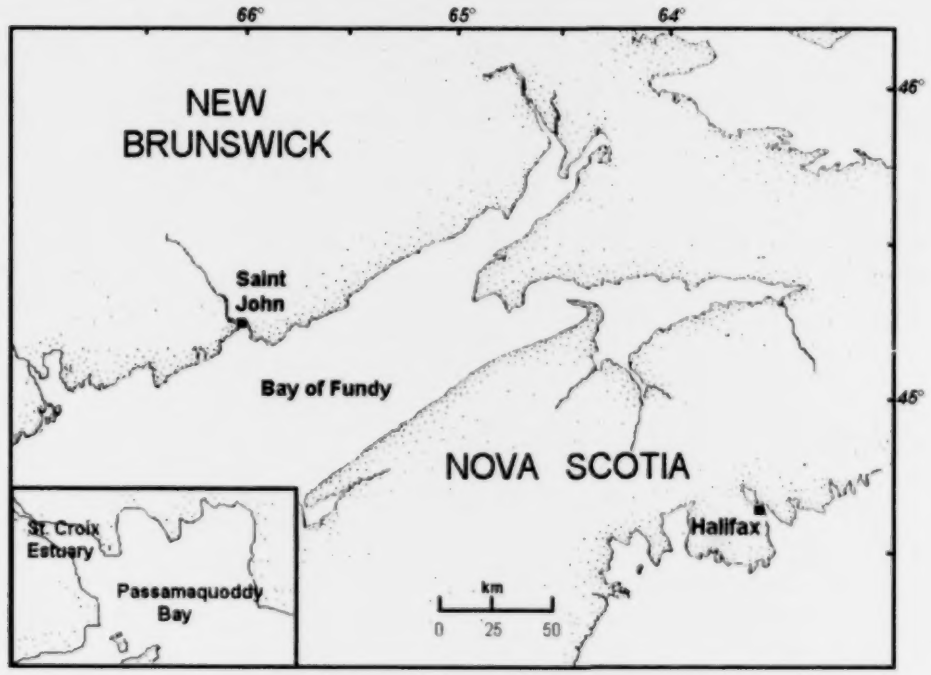

Figure 1. Passamaquoddy Bay, Bay of Fundy, Atlantic Canada.

Results and Discussion

In a study of EMP rating on sediment data collected from New Brunswick salmon aquaculture operation cage sites, principal components analysis (PCA) results showed disagreements and misclassifications in some ratings according to sediment metal and organic carbon data (Chou *et al.*, 2002). In the present investigation we examined sediment chemical variables (Cu, Zn, Fe, Mn, Li, Al, organic carbon) that might be

expected to respond to the environmental changes associated with the accumulation of the cage wastes. The responses include the trends of the metals, organic carbon, and particle size, the metal to metal interactions (Table 1), the disruption of metal inter-relations, difference of normalizations from natural background sediments, and trends related to the environmental monitoring rating of cage over the time of operation (Fig. 2).

Table 1. r-values for metals, organic carbon (O.C.) and <63 μm particles (clay) in A (normal), B (hypoxic), C (anoxic), and reference sediments from salmon aquaculture sites, (n=27 samples). Note: ** is >99% level of significance, * is 99% >p>95% level of significance.

	Al	*Cu*	*Zn*	*Mn*	*Fe*	*Li*	*O.C.*
Al							
Cu	-0.5001**						
Zn	-0.5635**	0.7991**					
Mn	0.3980*	-0.3970*	-0.6576**				
Fe	0.7424**	-0.2544	-0.604**	0.6859**			
Li	0.6953**	-0.003	-0.1565	-0.0316	0.6232**		
O.C.	-0.6118**	0.5769**	0.782**	-0.631**	-0.716**	-0.3092	
Clay	0.0458	0.514**	0.3234	-0.1884	0.0922	0.4443*	0.320

Because of difference between ratings based on sediment chemistry and EMP classification, a statistical regression model was developed to assess the degradation of the environment stemming from the accumulation of cage wastes was developed. In this investigation, the concentrations of sediment metals were used as independent variables and the EMP rating including A, B, and C sites, was the dependent variable. The unadjusted EMP model as shown has an R^2 of 0.653 (coefficient of determination) (Table 2). This model explains only 65% of the data for predicting EMP. This reveals the complexities of sediment determined by EMP alone due to heterogeneity of sediments, the difficulty of different underwater conditions, and visual assessment of sediment characteristics, around the cage sites. In consideration of this problem, the principal component technique was applied to the sediment data to cluster the similarity of metal, organic carbon, and particle variables to obtain the adjusted EMP ratings for aquaculture sites. The improved model is shown with an R^2 of 0.945. The prediction model described in this report using the changes of sediment chemistry at the aquaculture sites could be used to assess the cumulative ecological effects associated with the accumulation of aquaculture waste.

This study shows that assessment of the marine environment at aquaculture sites requires a tool beyond the environmental monitoring program (EMP) rating. The sediment chemistry response to changes in environmental conditions at the aquaculture sites clearly result in differences from natural background sediment levels. Those changes make the modeling approach feasible in this study and useful for interpreting the impact of the aquaculture activities to the environment. This

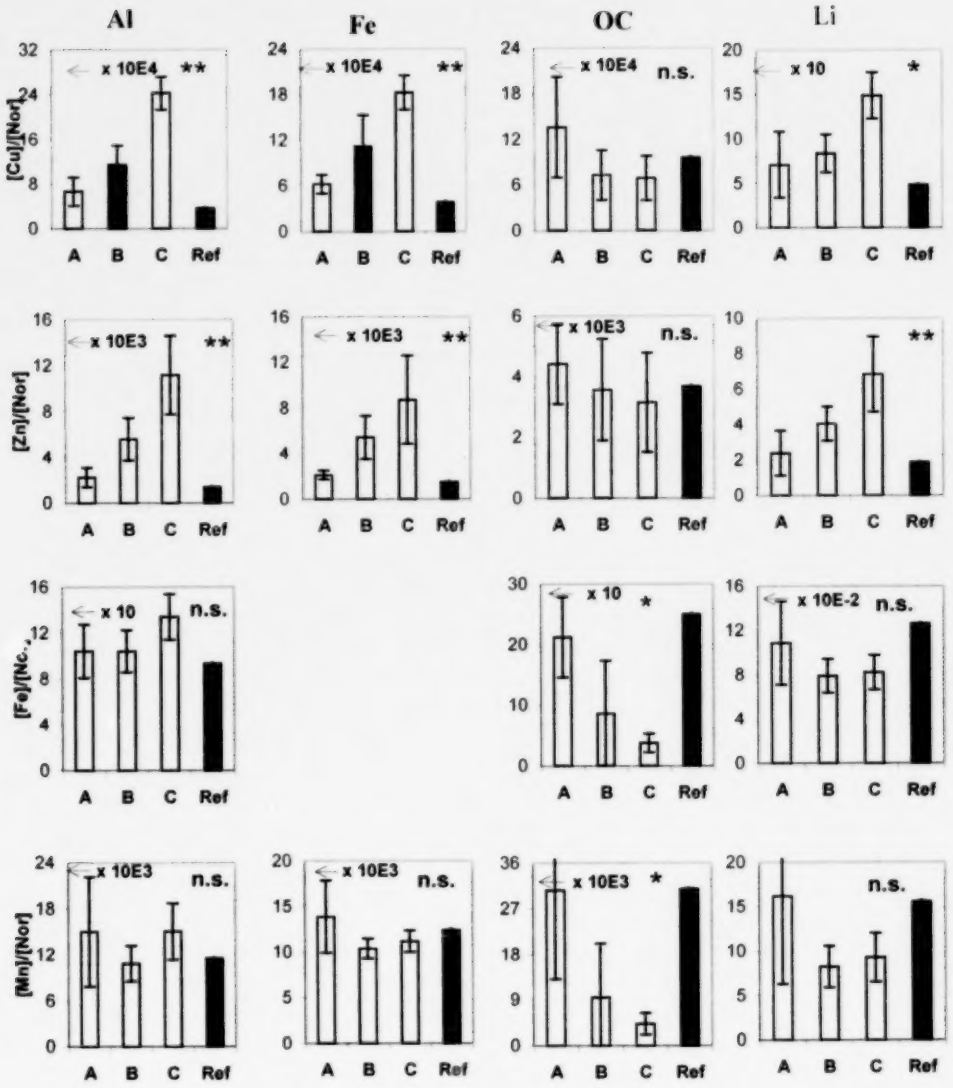

Figure 2. Means (± std deviations) for sediment Cu, Zn, Fe, and Mn concentrations normalised by Al, Fe, O.C. (organic carbon) and Li (** is p>99%; * is 99%>p>95%; n.s. is not significant. Note: A (Normal), B (Hypoxic), C (Anoxic), and Ref (Reference site)

Table 2. EMP regression models for aquaculture site sediments using variables of metals, organic carbon (O.C.), and <63 μm particles (clay), and coefficient of determination (r^2). Note: units for Al, Fe, O.C., and <63 μm particles are % and Li, Cu, Zn, and Mn are $\mu g\ g^{-1}$.

1. Unadjusted Model (by diver): EMP = 2.40 - 0.524 [Al] - 0.012 [Li] - 0.008 [Cu] + 0.004 [Zn] + 0.902 [Fe] - 0.005 [Mn] + 0.004 [O.C.] + 0.010 [<63μm] (r^2=0.653)
2. Adjusted Model: EMP = 4.72 + 0.071 [Al] + 0.021 [Cu] + 0.003 [Zn] - 0.398 [Fe] - 0.007 [Mn] - 0.055 [O.C.] + 0.003 [<63μm] (r^2=0.945)

approach provides an effective means for assessing the environmental conditions based on sediment chemistry, and consequently in establishing regulatory guidelines to establish baseline information, such as marine environmental quality, sediment remediation or degradation in relation to the aquaculture conditions.

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Environmental management and regulation for sustainable finfish aquaculture development in New Brunswick

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Responsibilities of the New Brunswick Department of Agriculture, Fisheries and Aquaculture (N.B. DAFA)

Presently in New Brunswick there are 96 salmon farms licensed and producing approximately 45,000 metric tonnes of Atlantic salmon valued at 250 million dollars and providing one out of every four jobs in Charlotte County. With the scope of the industry comes the need for the appropriate environmental management and regulation to ensure sustainable development. The Province has many policies, guidelines, and regulations that support the management and development of aquaculture, in particular this presentation focuses on the benthic environment and habitat issues, other issues encompass wildlife interactions, containment, debris, beach use and socio-economic considerations.

The first step in the process is to ensure the appropriate allocation of suitable sites for long-term sustainable development. This is achieved through the Bay of Fundy Marine Site Allocation Policy and Guidelines. These guidelines include among other requirements, a baseline environmental assessment, marine resource assessment and minimum physical criteria are set (current speed, depth and redox measurements). Through an extensive interagency referral, landowner notification, public advertisement, and fisheries consultation, sites that are approved are then issued licenses and leases to conduct fish farming. There are conditions set forth in the license that include the number of fish to be stocked, stocking density, maximum cage volume and in some cases additional monitoring and reporting requirements. Once approved, a site must commit to numerous conditions and yearly environmental monitoring regulated by the New Brunswick Department of the Environment and Local Government and NBDAFA through the *Aquaculture Act and Regulation.*

Many of the management initiatives that take place in the industry have included a scientific basis for decision-making, some of these initiatives include year class separation or buffer zones and the delineation of Bay Management Areas, relocation of sites to better locations, and yearly environmental quality objectives for the monitoring program.

Many specific policies, guidelines and committees exist that are involved in the sustainable development of the industry such as the; Aquaculture Site Evaluation Committee, Aquaculture Environmental Coordinating Committee, Bay Management Area (BMA) Advisory Committee, Aquaculture Site Remediation Committee, Duck Island Sound Sustainable Resource Planning Group, Exclusion Zone Review

Committee, Stakeholders Forum, Production Increase Guidelines and Crown Foreshore Users Working group. There are also Committees that deal with specific issues on the management of sites and include both levels of government and industry.

The results of specific research projects are frequently used in management decisions. Some examples include; research on aquaculture/fisheries and habitat interactions that use side-scan sonar and mapping of substrates along with sediment characteristics and populations of the fauna. Hydrographic modeling is used to define BMAs, determine separation distances between sites and identify suitable buffer zones between year classes. Remediation techniques such as harrowing have been examined to aid in mitigation at sites, and geo-chemical monitoring techniques are used for examining benthic sediment quality and form the basis for the environmental monitoring program.

Currently, there is a continuing need for science that is useful for the management of the industry. The continued communication between scientists, mangers and industry is vital. The research needs must be prioritized to be cost effective. The public must also have confidence that governments are using the best available science to make management decisions.

Responsibilities of the New Brunswick Department of the Environment and Local Government (N.B. DELG)

The reorganization of the government in 1999 resulted in the DELG gaining responsibility for the environmental monitoring and compliance for the marine aquaculture industry. This new mandate was to be met by including marine aquaculture within the Industrial Approvals Program currently in place under the *Water Quality Regulation – Clean Environment Act*. This resulted in marine aquaculture being subjected to the same regulatory process currently in place for other DELG-regulated industries in the province. During the period from 1999-2001, the Aquaculture Environmental Co-ordinating Committee finalized their Environmental Plan and DELG used this document as the backbone for the Environmental Management Guidelines (EMGs). After completing the consultation process, DELG adopted the EMGs as a policy document on which to base the Approval process and sets the environmental quality limits for the benthic environment below the cage sites and outlines a monitoring program in relation to those limits.

At present, DELG actively regulates contaminant discharge and its environmental effects covering a range of environmental issues, all relating to the prevention or limitation of the discharge of pollution to the environment. Within this context, the Approvals focus on the prevention of impacts to the benthic environment below cage sites. However, Approval conditions also cover overall waste management, chemical storage, noise control, and remediation as well as incorporate environmental monitoring and reporting requirements. In accordance with the *Water Quality Regulation* 6(1), all saltwater aquaculture operators are required to submit an application for an Approval to Construct &/or Operate. Operators must submit

Applications for new sites, modifications of sites and/or renewal of Approvals upon expiry.

Presently there are 95 marine finfish farms operating in Southwest New Brunswick with Approvals to Operate issued by DELG. The Department conducts routine site evaluations of each of these sites a minimum of once per year to ensure compliance with the Certificates of Approval. In cases of non-compliance, the Department has a thorough Compliance and Enforcement policy that outlines several options available to obtain compliance from Approval Holders. For the 2003 monitoring season (occurs annually between August 15 and October 15th), the results were as follows: 60 oxic, 33 hypoxic and 2 anoxic sites. Sites with hypoxic or anoxic ratings must submit remediation plans to the Department's Aquaculture Site Remediation Committee (ASRC). The ASRC provides advice to marine finfish aquaculture site operators in developing Remediation Management Plans (RMP) and advises the Minister of Environment and Local Government on the suitability of the RMP and their implementation through the Approvals to Operate and Schedules of Compliance. The committee is chaired by DELG, and has one representative from Environment Canada, Department of Fisheries and Oceans, and NB Department of Agriculture, Fisheries and Aquaculture.

Future plans include continuing to update the Approval's standards and guidelines for the Marine Finfish Approvals Program on an as needed basis and review policy options to ensure that they continue to be feasible for both the Department and Industry. The EMGs (and subsequently the Approvals) are subject to periodic review to identify any potential additional areas that may require environmental management and to ensure that the Approvals program remains in sync with any emerging environmental issues in the marine aquaculture industry. Any changes will come about as a revision of the EMGs &/or SOPs and all concerned government agencies as well as industry would be a part of that process to ensure that there would be no duplication of efforts between the various departments and to ensure that the concerns of everyone are addressed.

Water quality impacts of marine net-cage aquaculture facilities on commercial shellfish

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The sensitivity of shellfish to all types of water-born materials (e.g., metals, complex organic compounds, bacteria) make them appropriate candidates in the assessment of potential water quality impacts associated with salmon netcage operations. The use of shellfish as biomonitors not only permits us to test the spatial influence of these substances in the marine environment, but it has important implications with respect to sea food safety given their respective value in commercial (wild harvest, aquaculture) and recreational uses.

If the water quality issues related to marine netcage culture are quantified as minimal, or ideally non-existent, then a unique opportunity for shellfish-finfish polyculture becomes available. Product diversification from the finfish aquaculture sector's perspective makes such a venture a viable economic consideration, particularly given the opportunity of capitalizing on the use of existing infrastructure (transportation, anchoring, vessels, personnel, marketing, etc.).

Two study sites were selected for the research program, one an Atlantic salmon farm site (located in an area anticipated to have strong tidal flows) and the other a Pacific salmon farm site (in an area of weaker tidal circulation). To determine the potential pathways for waterborne contaminant transport at the two study sites, the physical oceanographic characteristics of the sites were documented at the onset of the study. Tidal circulation surveys of the entire study areas were conducted using a 300 khz Acoustic Doppler Current Profiler (ADCP) in transect mode, with lunar cycle exchange dynamics established using a bottom mounted ADCP. Tidal flow at one site was bi-directional (ebb and flow directions of 180 deg.) while data acquired at the other site revealed a uni-directional tidal flow (same direction regardless of tidal state).

Shellfish test longlines were installed at both farm sites, each positioned downstream of the farm to allow the established shellfish to intercept any waterborne contaminants from the farm site. Japanese scallops (*Patinopecten yessoensis*) and Pacific oysters (*Crassostrea gigas*) were placed at each of ten (10) stations positioned along these longlines, i.e., 0, 10, 20, 30, 50, 75, 100, 125, 175 and 225 m; an additional station was established within one of the system netcages to ensure signal detection of any waterborne contaminants. Seed and adults were deployed within Pearl nets and trays to facilitate ongoing performance evaluation (growth/survival) and routine sacrificial sampling (45-day sampling interval).

Sedimentation traps were also deployed at each of the study sites. A total of 15 canisters were placed at each site, with stations including centre (inside bottom) of the netcage adjacent to the longline, at the perimeter, and at distances of 10, 25, 50, 125, 150, and 225 metres downstream. Droplines for the canisters supported one at 15 metres below the surface and one near the seafloor. Sample residues were measured every 21 days (volume, weight) and analysed for trace metals, TOC and nutrient composition. OTC and Emamecten residues were also assessed in these samples during, and following treatment periods in 2003.

In addition to over 3,000 shellfish culture performance measurements (growth/survival), a total of 1,100 tissue samples and 180 sedimentation samples were analysed for some 35 parameters (trace metals, hydrocarbons, TOC, OTC residues, Emamecten benzoate, etc.) over a period of 2 years. Shellfish growth was not statistically signifi[illegible] at either of the farm sites. Mortality was less than 5% and typical of commer[illegible] shellfish aquaculture operations.

Dispersion of settleable organic wastes from the study farms indicated that although bottom accumulations occur to a distance of approximately 75-100 metres, the water column assessment suggests a dispersion limited to 30-50 metres (Figure 1). Shellfish tissue analyses reveal elevations above background to a distance of about 150 metres for oxytetracycline residues (following fish treatment with OTC). These tissue burden levels were associated only with the site characterized by reduced tidal flows (greater waterborne contaminant residency), and were temporal in nature (in situ depuration occurring within 30 days). Slight elevations in zinc also occurred within the shellfish tissues although these effects were noted only within 20 metres of the net-cages (low energy site).

Results of this study provide an accurate estimation of the "zone of influence" for the dispersion of waterborne contaminants, and have been employed in an assessment (from a seafood safety perspective) of the technical feasibility for developing integrated finfish-shellfish multi-trophic aquaculture (i-MTA) in Canada. This evaluation and discussion is currently being published elsewhere.

Acknowledgements

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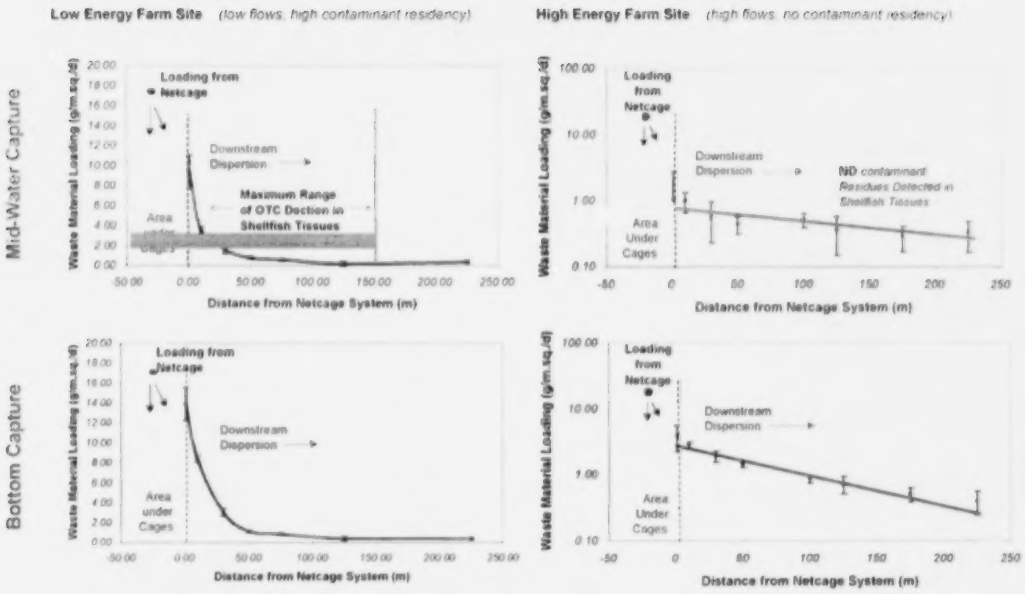
Low Energy Farm Site (low flows, high contaminant residency)
High Energy Farm Site (high flows, no contaminant residency)
Mid-Water Capture
Bottom Capture
Waste Material Loading (g/m.sq./d)
Loading from Netcage
Downstream Dispersion
Maximum Range of OTC Dection in Shellfish Tissues
ND contaminant Residues Detected in Shellfish Tissues
Area under Cages
Distance from Netcage System (m)

Figure 1: Dispersion and capture of settleable organic waste from each of the two study sites. Upper pair of graphs show spatial pattern of mid-water waste capture in downstream canisters while lower pair documents loading to seafloor along this dispersion pathway. Green text and horizontal bar illustrates corresponding downstream range of OTC bioaccumulation in shellfish tissues samples – detection of these residues, while temporal in nature, are limited to the farm site with minimal water exchange (increased waterborne contaminant residency).

A performance architecture for the Department of Fisheries and Oceans' Aquaculture Policy: Steps to put policy and potential into practice

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Developing and implementing public policy can be a murky business. Deciding on the best means to achieve the desired future state or outcome can be like a voyage into an ocean abyss: dark, uncertain, mounting pressure on all sides. The challenges facing public servants in achieving results are in many ways more arduous than those facing counterparts in the private sector. It could be argued that this is due to a more complex matrix of constraints, stakeholders and interest groups that must be consulted and appeased in the public and political realms. But, while these are complicating factors, they cannot alone account for policy faults and failure to realize the desired outcomes.

It is the author's contention that a far more critical area, often overlooked, is the lack of a rigorous and systematic approach to policy implementation. Public policy implementation deserves the same level of thorough and critical analysis that is demanded, indeed, legislated for large public works projects. The fact that social, economic and environmental strains are more difficult to calculate than the stresses in engineering materials is no excuse to exempt aquaculture policy expenditures from similar scrutiny.

The decisions of Cabinet and senior public servants are based upon highly condensed overviews of the policy problem and potential options. The question is frequently reduced to selecting one option that can be implemented to address a problem. The cabinet's involvement essentially ends with the instruction "Make it so". Therefore, the decision to launch a policy initiative is based upon what could be characterised as an artist's impression of the desired future state. However, unlike the sod turning for a new building or bridge, the launch of a new policy initiative is not automatically accompanied by detailed schematics, material and resource requirements, construction schedules and critical path analyses prepared and critiqued by successive layers of architects, civil engineers, planners and project managers. Cabinet does not give specific instructions to engage in such detailed preparations. It is simply understood and accepted that this work is necessary in advance of erecting the framework to ensure the structure will be suitable for the purpose intended. – But what of the policy initiative? Once it has been launched without a similarly rigorous mechanism to systematically map the steps and the resources required to move from concept through implementation to outcome, how can its effectiveness and ultimate utility be assured?

In order to achieve a desired outcome, a myriad of course alternations and compromises are inevitable to deliver a program within budget. Successful course alterations require regular position fixes are recorded to confirm progress and that

these positions compared to the course line first laid down on a chart from the point of departure to the destination. Simple measures perhaps, but no voyage can be made without these planning, progress and feedback loop. It is precisely this type of information that Performance Architecture and Strategy Mapping effort of the Aquaculture Coordination Office (ACO) will provide.

Why is public policy so difficult to implement? There are many reasons, but the principal causes are summarized below:

- Poorly understood relationships between program drivers (outputs) and outcomes
- No link between goals, strategies and actions
- No feedback on progress towards goals
- Disjointed planning and measurement processes
- Financial planning NOT linked to strategy
- No way to evaluate improvement initiatives and operational changes.

The approach developed by ACO staff draws upon the experiences and the work subject experts during internal aquaculture focus sessions, recommendations from the four DFO National Workplace Improvement (NWIP) Teams, provincial/federal working groups and best management practices used in other private and public sector organizations. It is not an attempt to reinvent the wheel or to add more axles to an already overloaded bureaucratic bus, but rather to create a practical means of providing public servants with a dashboard of essential planning, implementation and performance information on their desktop computers using existing software programs. Unfortunately, corporate or enterprise data systems are forensic tools for accountants and cannot function as active management systems. It must be stressed that this approach aims to provide tools to the practitioners with valuable management information, which cannot be gleaned from corporate systems.

The ACO has constructed interlinked modules that bridge the Aquaculture Policy implementation gaps. This presentation will outline the origin and the content of the policy strategy map, logic model, accountability matrix, resource requirement table, performance measures and scorecards, as well as illustrates how they will function in practice as this region implements the Aquaculture Policy Framework.

Application of a high resolution circulation model to aquaculture issues in the Quoddy Region

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Adapted from Introduction and Conclusions in Greenberg, D.A, J. A. Shore, F. H. Page and M. Dowd. (2004). A finite element circulation model for embayments with drying intertidal areas with application to the Quoddy Region of the Bay of Fundy. Ocean Modelling (submitted).

The nearshore ocean environment is subject to many stresses resulting from increasing human activity including aquaculture, fisheries, recreation, sewage inputs and marine transportation. An understanding of the physical oceanography of nearshore areas provides a foundation for the study of processes such as sediment transport and biogeochemistry, as well as a basis for effective management of the coastal zone. One potentially important physical attribute of many embayments which is often neglected in coastal circulation models, is the presence of significant drying intertidal areas. Models without the capability of simulating the dry areas may have errors in the area of the wet domain and/or in the volume of water within the domain. It is the purpose of this study to provide a means to effectively model the nearshore hydrodynamics of intertidal drying areas through the inclusion of a new algorithm in a comprehensive, finite element numerical circulation model. With this addition, we will be able to take advantage of the finite element variable resolution to include detailed nearshore topography and coastlines without sacrificing a realistic representation of the physical processes.

We want to emphasize that the purpose of including drying areas in a fully nonlinear three-dimensional model is to get useful results in non-drying areas. This is achieved by better approximating the effects of dynamically constricting and closing off channels and accounting for the proper volume exchanges of water in the nearshore. Although we want qualitatively defensible results, the use and verification of the model in and immediately adjacent to these intertidal areas is not the goal. Observational verification in such areas would be a significant challenge which we are happy to avoid.

Our tests on an idealized mesh indicate our goals are being met. Progressive flooding and drying over shallow bathymetry is as we would qualitatively expect. The characteristic shallow water tidal asymmetry in elevation is reproduced. The extreme resolution tests of a minimally resolved (single node width) narrow channel with drying sides and the isolated tidal pool show no anomalous behaviour and do not produce the spurious noise that can be found in primitive equation models.

We have applied the model (QUODDY_dry) to the Quoddy region of Southwest New Brunswick, Canada and compared the results with the associated fully nonlinear model (QUODDY) without the drying routines and with a linear harmonic model (FUNDY). FUNDY computations involve a one step solution and take only seconds to solve on any modern desktop computer. We note that for approximate harmonic solutions, this model is very efficient. The nonlinear and nonlinear-drying models take hours on present day single processor desktop computers. If QUODDY is run explicitly with the same time step as QUODDY_dry, the computation times are very close. When run implicitly, the time step could be doubled giving half the run time, indicating the stability requirements of basic implicit model are not greatly different from the drying model. This would suggest that QUODDY_dry is definitely more expensive to run, but not prohibitively so.

The three models gave very similar results in calibration to the M2 tidal elevation data. There were small successive improvements from FUNDY to QUODDY and QUODDY_dry. We believe the minimal phase variation in FUNDY demonstrates the importance of nonlinearities in this region. High tidal elevations and currents, the frictional terms, advection and time-varying depth, absent in this linear model, are all significant for these computations. The further improvement in calibration seen in QUODDY_dry over QUODDY may also be related to these nonlinearities. The better inclusion of the shallow areas enhances bottom friction and further emphasizes time-varying depth. QUODDY_dry's spatial resolution of the shallow water bathymetry contrasted to the uniform minimum depth of QUODDY, leads to spatial variation in the currents giving rise to larger advective terms. Another significant factor in the improvement could be the better definition of or even complete drying of shallow channels. An example of this is found in the comparison of currents in Back Bay from QUODDY and QUODDY_dry. Back Bay is separated from Lime Kiln Bay by a shallow area that effectively dries at low tide. Even though the elevations from the models are almost identical in amplitude and phase, the currents are very different. These current amplitudes are smaller in QUODDY_dry by a factor of about two. The difference in the phasing of the tide is about one hour.

Applications of this model have included particle tracking to examine the spread of disease, determination of minimum currents for oxygen resupply to aquaculture farms and relating the currents to sedimentation regimes. The more accurate currents of QUODDY_dry will give much more confidence in these computations. We feel the model is a useful improvement in high resolution tidal modelling of shallow areas. Work is continuing on several fronts. Our application to the Quoddy Region will be further developed. Calibration mismatches will be investigated for several aspects, including: examining wider parameter ranges, the collection of more calibration data, further increasing resolution in Cobscook Bay and critical channels, and runs that will include multiple tidal constituents. These will improve our particle tracking ability, and provide for improved bulk measurements of mixing within the Quoddy region. The model is also being applied to other areas. Further enhancements will include wind stress, computations in spherical coordinates and prognostic computations of salinity and temperature.

A decision-support system for evaluating new salmon farm site applications

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A major objective of the ESSA project was to interpret, synthesize and communicate research results to provide Habitat Management Division with advice useful for avoiding or mitigating potential environmental effects due to a HADD of fish habitat (Ross and Knapp 2001, Ross 2002).

While authorization letters may be issued, a preventative approach with close attention to siting criteria seems to be a preferred way to avoid a potential HADD associated with locating new aquaculture sites. A computer-based siting decision system (DSS) was developed based on criteria specified in DFO's Aquaculture Site Application - Review Process and Guidelines (Office of Sustainable Aquaculture, Ottawa). The guidelines, used by both Habitat Management and proponents of new aquaculture site development, provide a set of basic questions that form the basis of the DSS. Input data is derived from license applications for variables used as indicators of environmental alteration due to organic enrichment considered under the Canadian Environmental Assessment Act.

The DSS is currently available as a series of web pages on the DFO intranet with password access that allows tracking of users and evaluation of processed applications. It assesses far- and near-field variables potentially affected by marine finfish aquaculture based on answers to sets of questions to indicate if a proposed site has characteristics that might lead to a HADD following license approval. The PC-based program provides objective scientific feedback on site assessments to support decisions of habitat managers. It compiles information on physical, chemical and biological variables associated with a licence application in a structured database and assigns unbiased cumulative scores to provide advice on the environmental feasibility of the proposed site location

Data is input into the DSS is on three web pages:

Locations Variables:

1. Location and application number (Navigable Waters Act unique code)
2. Name of applicant
3. Geographic location by name and geo-referenced co-ordinates for four corners (outer boundary) of the proposed lease site
4. Species to be cultured
5. Number and sizes of cages
6. Stocking density

Ecosystem (far-field) Variables:

1. What is the distance from the proposed lease site to a shellfish closure area (km)?
2. Are there wild species harvested for food within 2 km?
3. Are there existing and active aquaculture sites for salmon culture within 2 km?
4. Is there a MPA or other protected area within 5 km?
5. Are there endangered species within 5 km?
6. Does river discharge occur creating water column stratification?
7. Is there a sill present within the inlet system preventing sub-surface water exchange?
8. Are there any industries (pulp paper, fish processing) within 5 km?
9. What is the number of people living within 1 km of the proposed site?
10. Is there critical fish habitat (spawning area) within 1 km of the proposed site?

Site-specific Variables:

1. Inlet area (headland-headland) (km^2)
2. Lowest low water depth (m)
3. Tidal amplitude (neap-spring cycle)(m)
4. Mean peak current for measurement period ($cm\ s^{-1}$)
5. Mean percent dissolved oxygen (seasonal minimum) in the upper 5 m of the water column
6. Secchi disc depth (transparency) (m)
7. Percent silt-clay (fraction of sediment <5 μm)
8. Total organic matter in sediment (% of dry weight lost on ignition at 550 °C)
9. Total sulfide in sediment (μM)
10. Redox (Eh) potential (mV)
11. Number of sediment sampling locations
12. Duration of current measurements (number of days)

Positive to negative scores are assigned to each ecosystem and site-specific question based on pre-determined qualitative and quantitative variables. Specified threshold values are assigned for an area (for example the Western Isles region of the Bay of Fundy) where sufficient background data exists to serve as a baseline against which to measure changes.

The DSS provides an effective and legally defensible method for screening applications. It streamlines information requirements for the proponent. It is also flexible (new questions can be added and regional differences in criteria and thresholds can be incorporated) and provides a consistent set of questions for evaluating site suitability. Scores for selected variables can be weighted and revised criteria and thresholds for scoring can be used to reflect regional differences, additional scientific information or changes in licensing regulations. Application of the DSS also identifies deficiencies and areas requiring enhanced management. Habitat Management (Maritimes Region) is currently evaluating the DSS as a screening tool and aid to process new license applications.

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Ecosystem indicators of water quality
I: Plankton biomass, primary production and nutrient demand

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Seasonal measurements of plankton (phytoplankton and bacteria) biomass and abundance, primary production, and nutrient demand were conducted in coastal waters of southwestern New Brunswick (SWNB) in 2000-2002 to investigate the far-field effects of finfish (salmon) aquaculture on the pelagic ecosystem. Plankton biomass and production varied seasonally with peak concentrations and activity in summer-fall and lows in winter. Nutrient demand followed a similar pattern with nitrogen (nitrate and ammonium) turnover times ranging from greater than a week in winter to less than a few days in summer. Evidence of increased nutrient concentrations, elevated plankton biomass and higher primary production and nutrient demand as a consequence of aquaculture activity was lacking based on comparisons between farm and control sites and considering the similarity of the nutrient and plankton cycles observed to those seen in other undisturbed coastal waters. Several lines of evidence point to the conclusion that primary production in SWNB is under light control and that phytoplankton there have limited capacity to process additional nutrients produced as aquaculture in the region expands (Fig. 1). The ratio of bacterial abundance to phytoplankton biomass (B/P ratio) is proposed as an easily measured water-quality indicator for assessing the trophic balance (autrophy versus heterotrophy) of the pelagic ecosystem in coastal waters.

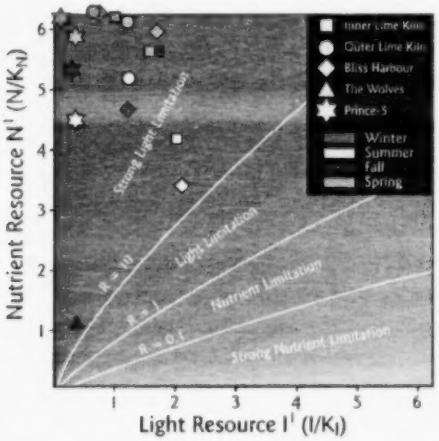

Figure 1. Index (R) of light/nutrient-limitation:
R>1 = light-limited, R<1 = nutrient-limited

Apportioning sources to PAH, PCB and DDE detected in sediments around aquaculture cages

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Thirty percent of the salmon produced by aquaculture in Canada are located in the south-western New Brunswick. This industry has been increasing in size since the 1970s and the impact of wastes generated by salmon faeces and feed deposited under cages needs to be determined (Burridge et al, 1999; Keizer, 1994). A large variety of organic and inorganic chemicals can be linked to aquaculture (Zitko, 1994). In the present publication, impacts refer specifically to the detection of three groups of lipophilic priority organic contaminants in sediments underneath the cages, and up to 100m away from the cages, in the direction of the currents. Contaminants would derive from the deposition of excess feed given to salmon and would be expected to be present in fish faeces. To have an idea of the possible level and variety of PAH, PCB and chlorinated pesticides in feed, five commercial feed as well as a fish oil used by industry were purchased locally and analysed. The fingerprints observed in feed form the basis of interpreting sediment results. Priority pollutants, ubiquitous in the marine and terrestrial environments, have been linked to a number of toxic effects in biota. Some compounds have been shown to be mutagenic and/or carcinogenic and can affect reproductive, neurologic and immunologic systems (e.g. Delistraty, 1997; McFarland and Clarke, 1989; Mousa et al, 1998; Short et al, 1997).

Sediments were collected over three consecutive years, 1998-2000, from 14 sites during the first year and 28 sites over the last two (Hellou et al, in preparation). The concentrations of contaminants, along with lipid content of feed or total organic carbon content of sediments (TOC; Chou et al, 2001) were determined. All samples were analysed according to published procedures, with best laboratory practices of quality assurance/quality control, i.e. each batch was processed along with a blank, duplicate and standard reference material (Hellou et al, in preparation). Samples were collected in co-operation with the New Brunswick Department of Agriculture, Fisheries and Aquaculture (DAFA) and the New Brunswick Salmon Growers Association (NBSGA) during their annual surveys of salmon aquaculture sites. Samples were identified according to site classification and numbered for location. Sites are rated by the province as A, B or C, depending on estimated impact on the seabed, which relates to the level of oxygen in sediments, where C is most impacted and anoxic, B is hypoxic, while A is least impacted (oxic; Burridge et al, 1999). Results of analyses were interpreted relative to the New Brunswick ranking, comparing data between years and with distance from under the cages. Due to confidentiality requests by the NBSGA exact locations remain unknown except to the commercial Scuba Diving Company.

Feed size ranged from 1 to 10 mm, with a lipid content of 20.6-30.5%, with two samples coming from one company and having more than 25% lipid, displaying higher concentrations of PCB, DDE and alkylated naphthalenes (alkNA) than the other samples. Unlike the rest of the feed, the smallest size feed given to salmon fry also displayed the presence of more parental PAH (90% of sum). Some PAH, such as fluorene and phenanthrene were present in only some of the samples. Anthropogenic sources of PAH are ubiquitous in the environment. These lipophilic molecules derive from either combustion processes or fossil fuel products, with a smaller number of PAH having a biosynthetic origin. The detected alkylated derivatives are generally more abundant in feral marine finfish analysed whole or as fillets, while benthic feeders or borrowers have been associated with a broader range of PAH, especially in internal organs (Hellou and Warren, 1997; Hellou et al. 2004, in press).

Non-detectable levels of PCB were determined in three feeds with lower lipid content (<25% lipids and < 1 ng g^{-1}). A maximum of 14 of the 159 analysed PCB congeners were detected in samples, with IUPAC congener 153 (co-eluting) being the most abundant. Twelve organochlorine pesticides were targeted for analysis, only p,p'-DDE was present in most samples, while p,p'-DDD was also detected in all feed. PCB and DDT were produced synthetically until the 1970s, when they were banned in North America and Europe. However, DDT is still manufactured in other countries, with an intent to phase out its use, as successful pesticide alternatives are discovered. Within the DDT group of compounds, DDE is the primary degradation metabolite of DDT, while DDD is a metabolite of DDE.

Concentrations of five alkNA present in all analysed feed and one fish oil, PCB IUPAC #153, p,p'-DDE and total organic carbon were generally higher under the cages than further away during the first two years of sampling. In contrast to this observation, the sum of the rest of the PAH tended to be more elevated away from the cages indicating a more contaminated environmental background. The level of contaminants varied over the years, per type of contaminants and per site, but remained lower at A, than B and C sites, for all groups. Therefore, the levels of contamination follow the New Brunswick rating of sites. Highest levels were observed in 1999 and are somewhat comparable to those determined by Loring et al (1998) in the nearby St. Croix river. Generally, levels of contaminants were lower on the third year of sampling, while the tendencies previously observed with distance were not maintained. For example, 1 B site displayed an increase in TOC, %alkPAH, PCB and DDE, with distance, while another B site displayed a decrease in TOC, % alkPAH, PCB and DDE, with distance (Figure 1).

It is also of interest to point out that PAH, PCB, DDE levels were 3-4 times higher at a remediated site in 1999 compared to the 1998 results, however TOC was similar. Remediation of the aquaculture sites needs more attention.

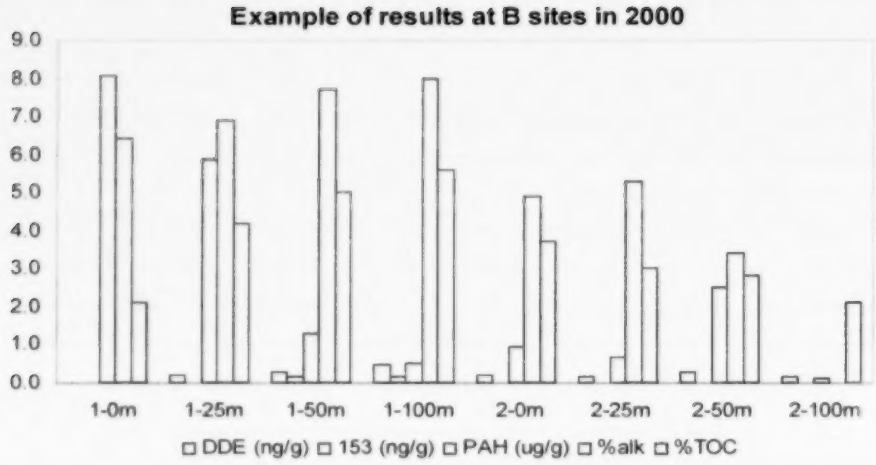

Figure 1. Numbers on the abscissa relate to site (1 and 2), followed by distance (0, 25, 50 and 100 m). The legend refers to p,p'-DDE, followed by PCB IUPAC congener 153 (co-eluting), the sum of PAH, the percent of 5 alkylated PAH (detected in all feed and one fish oil) and finally the total organic carbon content.

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Ecosystem indicators of water quality
II: Oxygen production and oxygen demand

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Seasonal transitions from biological oxygen production (BOP) to oxygen demand (BOD) can be defined in terms of the production-respiration (P/R) ratio in offshore surface waters and at coastal aquaculture sites in southwestern New Brunswick (SWNB). During the summer when P/R>1, a net autotrophic ecosystem is in place and dissolved oxygen (DO) remains above thresholds for optimal fish growth. During the fall and winter when P/R<1, a net heterotrophic system is in effect with a far greater potential for DO to decrease below threshold. Photochemical decomposition and oxidation can act as a seasonal link, triggering the rapid onset of BOD by allowing both terrestrial and marine organic carbon to be rapidly broken down in the fall.

As Harrison et al (2004) have pointed out, the SWNB ecosystem is strongly light-limited. In this environment, the phytoplankton cannot handle all of the nutrient load. Instead, the bacteria (as part of a phytoplankton-nutrient-detritus-bacteria ecosystem) draw down excess nutrients (Fig. 1) and create a sustained BOD that will continue until the nutrient supply is exhausted.

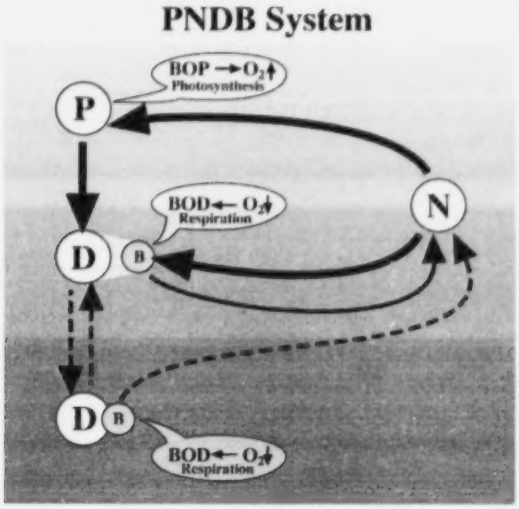

Figure 1. Phytoplankton-nutrient-detritus-bacterial (PNDB) ecosystem in coastal water and sediment. Note that nutrients supply the growth of bacteria and biological oxygen demand (BOD) as well as the growth and biological oxygen production (BOP) of phytoplankton. In the light-limited SWNB ecosystem, the nutrient-fuelled growth of bacteria will predominate.

Even though it is ultimately responsible for BOD, overall carbon load is not a useful index of the bioreactive material that creates oxygen demand. Instead bacterial number and chlorophyll concentration (expressed in terms of the bacteria:chlorophyll or B/P ratio) may be better indicators of ecosystem response and its regulation of seasonal oxygen dynamics (Harrison et al. this report).

If the seasonal change of P/R from greater to less than 1 is an early warning of the onset of BOD, then low DO is the cumulative effect of sustained BOD. Within this context of early warning and cumulative effect, the two indices (BOD and DO) can be integrated into ecosystem-sensitive plans for the management of oxygen depletion and water quality at aquaculture sites.

Phytoplankton and harmful algal blooms (HABs) in the Bay of Fundy

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A phytoplankton monitoring programme was initiated in 1987 in the southwest Bay of Fundy (Quoddy region) to study phytoplankton at a number of locations including the following: Brandy Cove, Lime Kiln Bay, Deadmans Harbour and the Wolves Islands. Purposes of the programme include: studying the whole phytoplankton community (for research purposes), establishing baseline data, acting as an early warning to shellfish regulatory agencies and salmon aquaculture industries, determining patterns and trends in phytoplankton populations, establishing some predictive or hindcasting capabilities, determining linkages with the physical and chemical oceanography, and determining possible effects of aquaculture on the environment.

Cell densities of all observed phytoplankton, including harmful algal species are recorded. Although more than 150 different species have been observed, most are harmless and do not produce toxins. Harmful species that have been observed include: *Chaetoceros convolutus*, *Gyrodinium aureolum*/ *Karenia mikimoioti*, *Mesodinium rubrum*, *Prorocentrum minimum*, *Chaetoceros socialis*, *Dictyocha speculum* and *Eucampia zodiacus*. The toxin producing species of major concern in the Bay of Fundy are *Alexandrium fundyense* and *Pseudo-nitzschia pseudodelicatissima*, the organisms responsible for paralytic shellfish poisoning (PSP) and amnesic shellfish poisoning (ASP, domoic acid poisoning), respectively. *Dinophysis* spp., organisms responsible for producing diarrhetic shellfish toxins have also been observed in Bay of Fundy waters.

PSP toxins in bivalves such as the soft-shell clams (*Mya arenaria*) have a long history in the area, with annual (generally summer) closures to harvesting due to unsafe levels of PSP. Blue mussel (*Mytilus edulis*) harvesting was suspended in 1944 in order to assess the extent of toxin retention in tissues and the Bay of Fundy and remains closed to blue mussel harvest. Other industries that have been affected include the herring (*Clupea harengus harengus*) where hundreds of tonnes of herring in the Grand Manan area died in 1976 and 1979 as a result of the accumulation of lethal concentrations of PSP toxins via the food web through zooplankton (White, 1980). In subsequent studies, toxins were detected in gut contents of a number of species of fish, but the muscles were safe for consumption (White, 1981). In 1988 PSP toxins were detected in Bay of Fundy Atlantic mackerel (*Scomber scombrus*) that had probably accumulated the toxins via the food chain through herring (Haya et al. 1990). It was further suggested that aquatic mammals such as porpoises, seals and whales that feed on PSP contaminated fish may suffer adverse effects. In 2003, mortalities of right whales were thought to be linked to PSP toxins - although further analyses indicated that domoic acid may have been responsible. Also, in 2003 salmon mortalities occurred during a redtide event of *A. fundyense* (>400,000 cells·L^{-1}) in salmon cages off Grand Manan Island. During the bloom period, low levels of PSP toxins were detected in gut contents of dead salmon. PSP toxin levels of 112-1200 µg (100 g STX

equiv.)$^{-1}$ were found in lobster hepatopancreas and blue mussel toxicity reached 18,000 and decreased to 4100 µg (100 g STX equiv.)$^{-1}$ in one week.

Alexandrium blooms generally occur in the months of May, June and July and occasionally in August and September. Some results from analyses of data collected since 1988 show the following: there can be from 1-3 bloom events during a given year; mean cell concentrations are generally the least at Brandy Cove and the greatest offshore at the Wolves; the mean bloom durations were shortest in the inshore; and there is considerable interannual variation in cell concentration. Numbers of *A. fundyense* tend to increase a few days before shellfish toxicity increases. Results suggest that cell concentrations as low as 200 cells L^{-1} can result in detectable levels of PSP toxins in shellfish. PSP shellfish toxicity data provided by CFIA from Lepreau Harbour and Lepreau Basin indicate that some years have high toxicity values. For example during the mid 1940s, early 60s, late '70s/early '80s and during 2003, shellfish toxicities were higher than other years.

Blooms of *P. pseudo-delicatissima* occur annually, and tend to occur during the May/June period and again in August/September. There is a great deal of interannual variability in this species where cell densities can vary from several thousand to more than a million cells/L. Domoic acid levels above the regulatory level have been detected in shellfish during the two years, 1988 and 1995 - when concentrations of *P. pseudodelicatissima* reach one million cells L^{-1}.

Results from the monitoring programme show an increase in numbers of species being identified. The following additional numbers (in parentheses) were documented for each period: 1993-96 (21); 1997-98 (15); 1999-00 (8); and 2001 (16).

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The effect of aquaculture on fine grained sediment dynamics in coastal embayments

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The aggregation dynamics of the particulate material and the hydrodynamics within any body of water will control the fate of fine-grained sediment. The formation and deposition of large, fast-sinking aggregates by flocculation governs the distribution of fine particulate material within the coastal zone. Three major factors control the development of a flocculated suspension: 1) particle number or concentration, 2) particle adhesion efficiency or stickiness, and 3) particle break-up, most often due to an applied shear. The steady state equilibrium size distribution of a flocculated suspension reflects a dynamic balance between particle aggregation and disaggregation, hence changes to concentration, composition, or turbulence can affect the distribution of fine particulate material and associated contaminants. The introduction of waste feed, faecal material, and their resulting degradation products from open cage aquaculture operations in the coastal zone will potentially increase both particle concentration and particle stickiness. As a result, the natural flocculation and depositional equilibrium of an inlet can become unbalanced towards increased deposition of fine-grained particulate material within flocs. The net result is a flux of mud into an inlet, with accretion occurring in areas of low bottom stress. Surface active contaminants associated with flocs will be sequestered with the fine-grained sediment. While no net accumulation of flocculated sediment may occur in areas of higher bottom stress, elevated concentrations of sediment could exist in the benthic boundary layer for biologically significant periods of time. The presence of flocculated sediment could lead to changes in species composition to those more tolerant of muddy environments. Evidence for such a shift in fine-sediment dynamics, contaminant transport, and species composition has been found in the Letang region of New Brunswick. (Fig. 1).

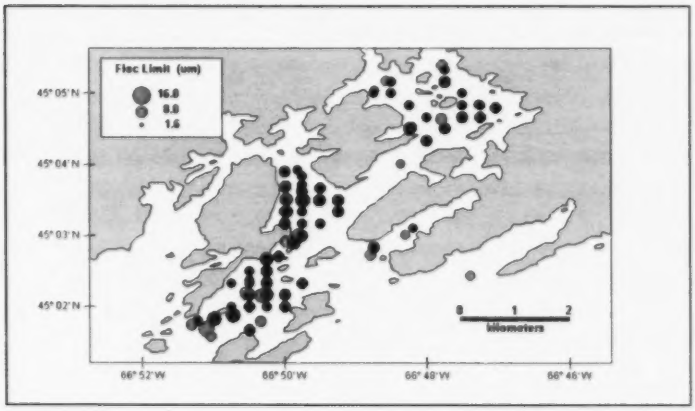

Figure 1: Thematic map of the Letang region (N.B.) showing values of floc limit, a parameter describing the degree of floc settling derived from the disaggregated inorganic grain size in surficial sediments for 1990 (black) and 1999 (grey). Floc limit has doubled in the depositional areas in Lime Kiln Bay indicating an increase in floc deposited sediment in areas of low bottom stress.

Changes in the environment due to the aquaculture industry, do they reflect an increased risk of disease incidences?

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A justifiable question is whether environmental changes due to fish farming cause new infectious disease situations and whether these introduce a significant or acceptable risk of detrimental effects to the environment including wild populations. However, the significance of possible environmental-linked disease link within the aquaculture situation should be placed in proper context. It is likely that changes in factors like growth performance, as evidenced by a reduction in feed conversion ratios, will probably become critical to the sustainability of a farm and require remedial action, well before most health concerns become apparent. When a disease agent (virus, bacteria or parasite) is present the subsequent development of a disease problem in a fish population is not inevitable. The development of an overt disease affecting a population has long been recognized to be a complex product of the interaction between the host (fish), pathogens and the environment but this model has now been recognized to be an oversimplification.

Several strict criteria must be fulfilled before a population becomes affected by disease:

- The surrounding environment (water) must contain susceptible host(s)
- Proper environmental conditions must prevail
- The pathogen must survive in the environment
- The pathogen must be exposed to a susceptible host by a route that allows infection
- The pathogen must be present in biologically significant numbers to initiate infection in the host.
- Once hosts are infected they must be able to transfer the infection to the susceptible population

With respect to our knowledge of diseases in aquatic animals, diseases affecting cultured populations are well defined because animals are confined, examined regularly for signs or symptoms of diseases and easily accessible for routine diagnostic testing. In contrast, our knowledge of diseases in wild populations is extremely weak because most of the information comes from animals caught during surveys or special research projects and most animals caught are usually healthy, otherwise it is assumed they would not survive and quickly become victims of predation.

Infectious salmon anaemia (ISA) is undoubtedly the most significant disease that has ever affected the salmon farming industry in Southwest New Brunswick (SWNB) and Maine. The disease was first detected in three sites in the fall of 1996. The unknown disease was originally named Hemorrhagic Kidney Syndrome (HKS). Confirmation

that HKS was in fact the disease ISA was only obtained in 1997. This is the most significant disease faced by the aquaculture industry. It has had serious economic impact and is solely responsible for most of the changes the industry has undergone for the last 7 years. Since 1997, each year class of Atlantic salmon has suffered variable losses due to ISA.

A better appreciation of the significant risk factors associated with ISA resulted in the Department of Agriculture Fisheries and Aquaculture (DAFA) preparing and enacting a comprehensive ISA control and management program. It is a multifaceted approach including increased disease surveillance, smolt placement restrictions, fewer holdover sites (reduction from 24 sites to only 2 sites by 2003), creation of a buffer zone in L'Etete passage, and harvest/service vessel and wharf restrictions. Site rationalization including increased distances between sites is another key element of this holistic approach.

In addition, surveillance, early removal of infected fish, fallowing sites and enhanced biosecurity measures can be viewed as the basic principles of the comprehensive ISA management program. Its implementation has resulted in ISA not being present in Lime Kiln Bay, Bliss Harbour and Back Bay in 2003 for the first time since the disease was discovered in SWNB.

It is recognized that risks should be identified and managed to an acceptable level. The adoption of an approach requiring absolute proof of no risk of adverse effects from diseases in aquaculture, prior to any development, is therefore unrealistic if aquaculture is to be accepted as a valid use of the aquatic resource. Although some correlation between data sets might suggest cause and effect relationships between fish disease and other factors, such as environmental quality, accepting them as proof is dangerous without a critical evaluation of other possible influencing factors. The modern approach for resolving these sorts of questions has been to use the principles of risk analysis, as outlined by the World Organisation for Animal Health (Office International des Epizooties) in the International Aquatic Animal Health Code. Risk analysis is a fast-evolving science. It helps regulators assemble data in a thorough and consistent way so their decisions can be made on a sound technical basis. Anyone affected by a decision is entitled to see the assumptions and decisions made during the process. Risk analysis is comprised of: hazard identification (What can go wrong?), risk assessment (How likely is it to go wrong?), release assessment, exposure assessment, consequence assessment (What are the consequences?), risk management (what can be done?) and finally risk communication. Risk analysis requires a multidisciplinary approach that is transparent. It must be realized that defining what is an "acceptable level of risk" is a difficult task and different stakeholders may have different or opposing views.

Several benefits can be achieved by using risk analysis. It allows:

- justify and defend its decisions;
- prioritize resources to the areas where risk is greatest;
- view risk objectively and realistically;
- identify research and information needs;

- identify technical points of difference between two opposing views

With respect to environmental changes caused by fish farming and the direct link these changes could contribute on disease severity and/or incidence, this question remains unexplained. Environmental changes do occur but their contribution to the overall health of salmon is still unclear. Disease event are complex and although environmental change can contribute to the severity or other aspects of disease issues, it is only one factor of many that needs to be considered.

As has occurred in the past, environmental changes due to salmon aquaculture can be expected as the industry expands. However, until new research is conducted understanding of relationships between disease outbreaks and environmental factors will be difficult to establish. A dedicated research program combining expertise in fish health and marine environmental science is essential to resolve unanswered questions. Research is currently underway in SWNB to link hydrographic factors of water mixing and exchange properties with spatial and temporal variations in the occurrence of disease. Risk analysis methods can be applied to quantify the severity of disease outbreaks, to identify the mechanisms involved in disease epidemiology and to develop effective management strategies.

Benthic macrofaunal changes in the Letang Inlet: a quarter century view of an industrialized area

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The Letang Inlet lies within the Western Isles region of the lower Bay of Fundy. Industries there have undergone major changes over the last three decades, including the start-up of a pulp and paper mill in the 1970's and the initiation of salmon aquaculture starting in the 1980's. Multivariate analysis of six stations spanning most of the Inlet indicated that benthic macrofaunal assemblages changed significantly between 1975 and 2000 in all areas of the Letang.

In 1975 benthic macrofaunal assemblages formed distinct groups changing progressively with increasing distance from the upper Letang, where untreated effluent entered the system starting in 1971. The change in benthic community structure was correlated with decreasing organic loading over distance, with Lime Kiln Bay, in the lower Letang, being least impacted at that time. The changing community structure in Lime Kiln Bay since that time is correlated with a significant increase in organic loading commencing in 1981. Unlike other Letang areas, bio-indicators showed a significant rise in taxonomic richness in Lime Kiln Bay. This change was associated with a significant shift in trophic structure toward deposit feeders. Dominating species in 1975, including the tube-dwelling amphipod *Leptocheirus pinguis*, were extirpated from the area by 1997/2000 and this trend extended to central areas of the Letang. Reference stations, in an area that did not experience such changes in industrial activity, did not show such dramatic changes over the same period of time. The observed regional changes in the lower Letang are consistent with broad-scale enrichment impacts from intensive aquaculture, ongoing to this day in that area. The absence of organic loading in Lime Kiln Bay prior to aquaculture indicates that organic enrichment from a fish processing plant, active at that time in an adjacent bay (Black's Harbour), does not contribute to organic loading of Lime Kiln Bay.

Conversely, in the upper Letang benthic macrofaunal bio-indicators showed a significant increase in average taxonomic distinctness between 1975 and 2000, coupled with a dramatic decrease in the abundance of the sludge worm *Capitella capitata*, the latter being an indicator of highly enriched conditions. Both changes are consistent with a recovery from those conditions in that region, as pulp and paper mill effluent entering the area there was properly treated starting in 1988.

Before aquaculture development (1975) benthic macrofauna community structure of the upper Letang was highly impacted by organic enrichment from pulp mill effluent,

while the lower Letang was free of impact. After development of the salmon aquaculture industry (1997/2000) macrofaunal communities in the lower Letang changed significantly. The changes are consistent with a general initial enrichment of the area, while the upper Letang recovered from highly enriched conditions as a result of treated effluent and the installation of a one-way flap gate, which prevented seawater entry above the causeway.

Impacts of eutrophication on the intertidal zone in temperate areas with emphasis on the soft-shell clam, *Mya arenaria*

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A change in the community structure in the intertidal zone is often one of the first indications that there are new stresses influencing the biota through eutrophication processes. The sources for the nutrient increases are numerous and often hard to pinpoint, but in general can be traced back to anthropogenic activities. In the Bay of Fundy, there has been an increase in the number of green macroalgal mats on some of the commercial clam harvesting beaches and it has been suggested by the fishers that these are a result of the development of the Atlantic salmon (*Salmo salar*) culture industry and the husbandry protocols. In some countries, research has shown that green algal genera such as: *Enteromorpha*, *Ulva* and *Cladophora* can respond quickly in growth to increased nutrient conditions and as a result, change the physical and chemical environment of the beaches impacting the infauna and recruiting larvae. In 2000, a study was initiated to investigate the potential far-field impacts of increased eutrophication on soft-shell clams that might be attributed to salmon aquaculture.

The first stage involved examining the historical data through aerial photographs of beaches located within the zone of intensive salmon aquaculture. Two sites were chosen, Hinds Bay, a soft mud beach at the head of two intersecting inlets with salmon farms (Lime Kiln Bay and Back Bay) and Clam Cove, an enclosed sandy beach at the south end of Deer Island with a salmon farm in the mouth. Aerial photographs of Hinds Bay indicated that algal mats covered about 4% of the surface area in 1994, but that this increased to 25% in 2000. However, in 2001, the coverage dropped back to 8% indicating that this beach could have substantial annual variation in coverage. Potential sources of nutrients in 2000 included the salmon farms in the

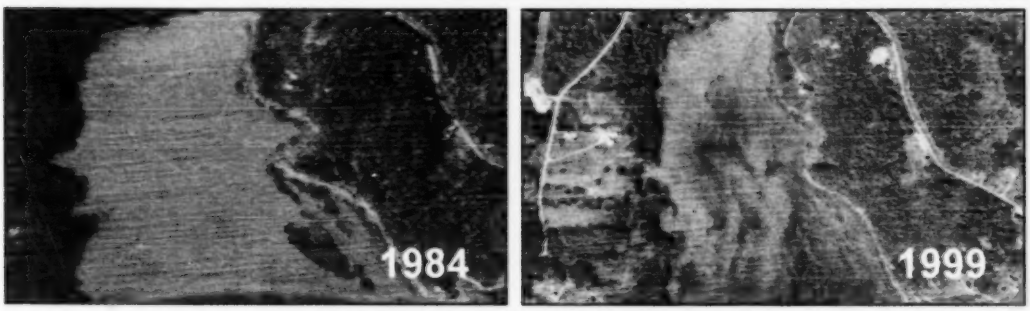

Figure 1. Aerial photograph of Clam Cove, N.B. showing progression of *Enteromorpha* mats from 1984 to 1999.

area, a fish processing plant at the head of the cove and a few houses. The Clam Cove site showed a dramatic increase in algal coverage. In 1984, algal coverage was less than 2%, but by 1999 it had increased to 33%. Between 1999 and 2001, algal coverage ranged from 32-48%. During the last 25 years, the human population on Deer Island decreased slightly and there was no evidence of increased industrial activity. These circumstantial data indicate that there was a reasonable probability that salmon farms were contributing to the increase in algal biomass in some areas.

We then examined whether there were any differences in clam densities underneath or away from the intertidal algal mats. In general, there were more clams away from algal mats than underneath, although there were two samples that showed higher densities under the algae. Clam population densities sampled ranged from 40 – 800 m^{-2}. There was substantial variability between samples in clam densities. We also noticed that the algae could expand relatively quickly so some of the observations of higher densities under algae might have been a result of the algae expanding over existing clam populations. Observations on the older algal beds indicated anoxic sediment under the algal mats where clams would often be observed laying on the surface of the sediment. To complicate the issue of relative calm density, there was commercial harvesting occurring on some of the sites as well that would have been targeted on clams living away from algae.

Morphometric samples were taken from the clam populations under and away from algal mats. Body tissues of clams were divided into two portions: mantle+gills+foot and gonad+digestive mass, dried to constant weight at 80°C and then weighed. The proportion of the body weight comprised by the gonad/digestive mass was found to be significantly lower for clams collected from under algal mats during the spawning season in June at one of the beaches. This suggested either a reduced reproductive output of the clams living under the algal mats or an altered spawning season. There were no differences observed between clams outside the algal mats and other reference beaches that were not impacted by algal mats. Further work is required on this potential effect of the algal mats.

To examine whether algal mats affected the behaviour of soft-shell clams, we measured the burial depth of the clams under and away from algal mats at two beaches. Clams of all sizes and in all months sampled were significantly shallower in the sediment under the algal mats. We also examined this behaviour in the lab by putting clams in aquaria (3 replicates) and subjecting them to a cover of 2 or 6 cm of algal mat. Clams placed under the algae immediately surfaced after the first day while the control clams remained buried (Fig. 2). Once the algae were removed from the aquaria, the treatment clams reburied. These data suggest the algal mats do have a dramatic effect on the behaviour of the clams forcing the clams to respond to being covered by surfacing in the sediment. The implication of this behaviour is to likely increase the predation rate as the clams abandon their depth refuge.

Whatever the source of nutrients, there is a financial cost to the coastal communities associated with the algal mats. For example, the area of Clam Cove was 19.75 ha. If there was a density of 75 clams m^{-2} then there would be a standing stock of 14.8

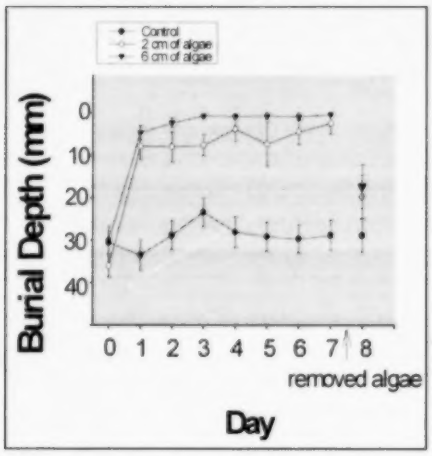

Figure 2. Burial depth response of soft-shell clams covered with either 2 or 6 cm of algal mat compared to controls (no algae).

million clams. At a harvest weight of 15 g each, there would be 222 t of clams worth $746,365 ($3.36 kg^{-1}). If 30% of the beach was covered with algae, the loss to the clam industry would be $223,909. This loss would happen whether the clams died or not because the diggers are not able or willing to clear large quantities of algae to harvest the clams. Conversely, if the algae were removed and sold (assume 30% coverage at 500 g m^{-2}) for $0.10 kg^{-1}, then the value of the product could be almost $3,000 and the clam production might increase.

The results of this study have shown that there was a biological effect of the green algal mats caused by eutrophication on soft-shell clams, both physiologically and behaviourally. Salmon farming operations were likely partially responsible for some of the algal build-up in some areas. The future challenges to society involving issues of eutrophication of the intertidal zone will be to deal with the increased ecological interactions caused by increased primary production. How we deal with this will depend on whether we choose a legislative impact route based on preservationist policies (i.e. turn off the nutrient tap) or whether we choose alternative solutions that encompass more systems control processes (i.e. systematically harvesting the increased production at multiple trophic levels).

Industry activity to support sustainable development and operation of marine salmon aquaculture

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New Brunswick (NB) salmon farming is the province's largest agri-food industry, with annual sales of over $270 million and employing over 4,500 direct and indirect jobs. Operating from 96 active marine farm sites, the industry supports 19 hatcheries and 10 processing plants. There are approximately 30 companies, mostly local owner-operated. About 25% of the jobs in Charlotte County are associated with salmon farming.

Activities to support sustainability of the industry take place in the development of new sites, operation of existing sites, and in efforts to rationalize production in some areas. Environmental assessment of new and changing sites provides a formal process to support sustainability. Regulated activities and best management practices are routinely implemented on operational sites. Changes in ownership and operational financing require due diligence processes to limit liabilities.

There are many reasons why these activities take place. Apart from legal requirements, corporate planning and community responsibility are important to the industry. There are practical requirements for farms to co-operate to maintain optimal environmental and fish health conditions. In addition, the need for financial sustainability has focused industry research and development on improvements in food conversion and reduction in waste generation.

Some of the codes of practice, or best management practices of the industry are:

- Site Marking Guide
- Introduction and Transfer Code
- Bay Management Area Agreements
- Waste Management Plans
- Cleaning and Disinfection Guides
- Wharf and Vessel Traffic Guide
- Fish Health Surveillance Program
- Healthy Salmon Program
- Harvest Plan, Code, and Audits
- Environmental Management Guide and Monitoring Program
- Habitat Management Agreements

In addition to these specific activities undertaken by the sites, the industry at-large and the New Brunswick Salmon Growers Association (NBSGA) participates in a proactive manner. This includes participation on working groups and stakeholder forums, co-operation and communication within and external to the industry,

providing data, information, and knowledge, and incurring additional costs and time to the business.

Industry will continue with these activities while incorporating the results of the ESSA project. The first step will be to achieve a better understanding of the results, to which the ESSA symposium is a positive step. Next will be implementation of the science in practice, with a focus on high priority and tangible issues. The industry, as always, will be directly involved in those issues while continuing to support issues of more broad coastal ecology application. Salmon farming in NB has developed through adaptation of knowledge and experience to local conditions; a process that should apply to the incorporation of the ESSA knowledge.

The time is right for enhancing sustainability of NB salmon farming through application of the ESSA results and further research and development. Recent informal discussions between DFO, the industry, and the province have all supported this direction. The industry proposes that a more formal, dedicated effort be conducted to determine how to move forward. An aquaculture - environmental sustainability forum that brought together key individuals with common goals and objectives could serve this purpose.

The NB salmon farming industry is a well-established and critical component to the rural economy, and takes a proactive approach to environmental sustainability at all levels of development and operation. Codes of practice, best management practices, and other initiatives are implemented to achieve regulatory compliance, to maintain optimal environment and fish health conditions, and to meet corporate and community expectations. These activities have developed and evolved to incorporate the best available science and knowledge. Incorporation of the results of the ESSA project should continue this process.

Geochronologies for fish farm contaminants in sediments from Lime Kiln Bay in the Bay of Fundy

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Sedimentation rates measured in a suite of sediment cores collected in the Western Bay of Fundy over a period of 25 years using the radionuclide tracers, ^{210}Pb and ^{137}Cs ranged from values <0.1 cm y^{-1} to values >1.5 cm y^{-1}. Sediments collected at distances >1 km from finfish farm operations exhibited little evidence for aquaculture impacts. However, sediment cores collected proximal to aquaculture sites in Limekiln Bay, which has been the location for extensive fish farm activity over the past 20 years, exhibit elevated levels of Zn (>250 μg g^{-1}) and Cu (>70 μg g^{-1}) in sediments in the upper 15 cm of the cores. ^{210}Pb and ^{137}Cs dating of the cores indicates that the sediment threshold horizons for elevated Zn and Cu levels conform to the initial introduction of fish farms into Lime Kiln Bay in 1981. The highest contaminant levels were measured in sediment cores collected within the "footprint" of previously abandoned sites with the sediment signals decreasing with increasing distance to values approaching background levels at distances of 200 m from the original cage locations. Zn and Cu concentrations remain elevated in sediments following the removal of the cages suggesting that the subsequent remobilization of these metals from the sediments is minimal. Other robust tracers of fish farm activities include P and Cd, presumably as a result of the deposition of biogenic material in the form of fish food pellets in a near shore depositional regime dominated by inputs of terrigeneous organic material.

Salmon aquaculture, nutrient fluxes and ecosystem processes in southwestern New Brunswick

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Sea-cage salmon aquaculture discharges organic wastes into the marine environment. In addition to the organic enrichment that results, salmon metabolism and the decomposition of the waste feed, faeces and urine consume oxygen and release nutrients, thereby adding nutrients to and removing oxygen from both the water column and surface sediments. When detailed information is available on farm operations, the amounts of waste discharged in a coastal environment can be determined from a budget of feed use and the number and size of salmon on site at each farm in the area. Such detailed data is not available in southwestern New Brunswick (SWNB). The SWNB example is used to illustrate how farm and bay scale waste discharges can be estimated in such a case. A fish growth model and mass balance calculations are used to develop farm scale estimates of carbon, nitrogen and phosphorus wastes. Physiological and environmental measurements can then be used to partition wastes into waste feed, faeces and urine, and to estimate the oxygen demand from salmon respiration and the breakdown of other wastes. In SWNB, maximum discharges occur in September of the second year of growth. The oxygen demand at this time is calculated to be 250 times greater than the median value of oxygen uptake measured in surface sediments at cage sites, suggesting that most farm wastes are dispersed over wide areas and do not accumulate in the debris piles under cages. The numbers of fish in a bay for each year class are then used to predict total discharges to coastal inlets. In SWNB, salmon aquaculture is the most significant anthropogenic source of organic matter loading in the coastal zone. The significance of the wastes on bay scales is also evaluated by comparing the fluxes of carbon, nitrogen and oxygen through salmon farms with fluxes due to natural ecosystem processes of phytoplankton and macrophyte growth, nutrient regeneration by plants and surface sediments, and community respiration measurements in the water column and surface sediments. In some bays with high density aquaculture, the ratios of fluxes through salmon farming to fluxes due to natural ecosystem processes reach values of 0.21, 3.6 and 2.0 for oxygen, nitrogen and carbon, respectively. These conclusions are robust: the impacts are much larger than the uncertainties in the calculations. Clearly, significant changes to both the structure and functioning of the ecosystem have occurred in these bays. Spatial scales are critical in describing such impacts: effects will be greater close to the farms, and smaller when averaged over larger areas.

Near-field depositional model for finfish aquaculture waste

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An analytical near-field depositional model for solids wastes from open net pen culture of finfish is presented. The model is based on the premise that the statistics of the depth-averaged currents determine the distribution of wastes on the ocean bottom. The model calculations are based on a bivariate normal distribution for the depth-averaged currents. Using a farm configuration consisting of a single net pen, the model is used in a diagnostic mode to quantitatively examine the effects on the waste depositional field or footprint of the farm that result from changing two key parameters, namely the depth under the net pens and the standard deviations of the depth-averaged velocity. The model is also used to examine the changes to the farm footprint that result from orientating a two by four linear grouping of net pens perpendicular to and parallel to the principle current direction. The predictive capability of the model was tested on an operating fin fish farm by comparing the model waste fluxes with the vertical fluxes of solids measured by sediment traps. Based on a rather limited data set, predicted waste fluxes are about 50% higher than observed sedimentation rates. Finally, the limitations and uncertainties in the model assumptions, parameterizations and in the methodologies used to validate the model are discussed.

Zinc in sediments as a tracer of fish farm wastes

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The results of metal analyses carried out on surficial sediment samples collected in the coastal waters of Southwest New Brunswick (SWNB) and the Broughton Archipelago in British Columbia have been used to investigate the use of heavy metals as tracers of salmon farm wastes. Both of these areas have seen rapid expansion of open cage salmon aquaculture in recent years. While techniques have been developed to identify benthic impacts directly beneath the cages, no method has been developed to determine the fate of dispersed wastes. We show that zinc (Zn) and copper (Cu), two elements associated with aquaculture operations, can be used to identify farm wastes in far-field sediments at some distance from the cage sites.

Geochemical normalization for grain size is needed in order to see the small tracer signals. Normalization with lithium has been shown to compensate for changes in grain size and mineralogy in physically weathered environments such those found on the east coast of Canada. In this study, we show that this method provides a good way to identify metal concentrations that exceed background concentrations. More traditional methods of identifying elevated concentrations fail to pick up these anomalies.

Excess Zn and Cu levels are found in the sediment remote from the salmon cages in depositional areas in southwest New Brunswick (SWNB) and in the Broughton Archipelago. The initial experiment identified farm waste deposition sites in Lime Kiln Bay and Back Bay in the Letang estuary. Subsequent experiments in SWNB showed the ability of the technique to identify deposition of farm wastes in intertidal sediments and at an additional farm site in Maces Bay that had only been in operation for a few months. Finally, measurements made in the Broughton archipelago in coastal British Columbia showed the applicability of the technique to the very different environments found on the west coast.

Evidence that links these observations to salmon aquaculture development is described. Our studies and those done by others have shown elevated concentrations of Cu, Zn and several other metals enriched in our far-field samples at sites immediately under farm cages. Dated Letang estuary sediment core results have shown that the initial increases in Zn and Cu concentrations occur at approximately 1980, a time that is consistent with the beginning of the aquaculture industry. Changes in Zn and Cu concentrations also co-vary with changes in sediment flocculation

characteristics that are associated with farm wastes. Suspended particulate matter (SPM) must be the vector for transport of farm wastes to the depositional sites. Measurements of metal concentrations in Lime Kiln Bay SPM, but not those in Bliss Harbour or the open coastal waters of SWNB, also show elevated zinc and copper concentrations.

REVIEWER'S COMMENTS

Scientific Overview of the ESSA Project

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This was the final presentation of the work carried out under the ESSA project and covered a wide range of topics. Given that the work presented was either complete or close to completion, a point-by-point discussion of individual papers is probably not of great value. Instead I will focus on trying to give an overall impression of what was and, more importantly, what was not done, and what should be the priorities for further development and application.

I hope that the emphasis that I place on work that still needs to be carried out will not be seen as negative. The Symposium was one of the most impressive meetings I have attended and the quality of the work and of the presentations was excellent. Certainly no one expected the study of aquaculture impacts to be fully resolved by a limited three-year study, and my role is simply to try to provide some guidance for the next stage of research. I have come neither to bury Caesar nor to praise him, but merely to be an advisor to his children.

What Kind of Science?

At the opening of the Symposium Mike Sinclair, Regional Director of Science for the Maritimes Region, stressed the importance of applied science and the need for science, at least that supported by public funds, to address the needs of the citizenry. Many of the talks were definitely applied and addressed specific concerns, and much of the research carried out in ESSA should be of immediate benefit to the industry and other stakeholders. However, there is always a need for balance between applied and basic research, and there were times during the Symposium when there was evidence of a lack of some of the fundamental science that was needed to answer pressing questions.

This lack was evident during the discussion of the final talk by Gilles Olivier, which touched on the issue of disease transmission between sites. As pointed out by Barry Hargrave, epidemiology was part of the original ESSA plan but had to be dropped because of time and resource constraints. The underlying reason is that epidemiological research cannot be dealt with on the scale of a project like ESSA. Transmission of fish diseases is a global problem which few agencies have been willing to tackle, and to which there are unlikely to be any quick answers. It requires far-ranging studies on factors such as the loss of infectiousness of pathogens under a wide range of environmental conditions which are unlikely to be satisfied by a small

number of site-specific projects. In the absence of such studies, every jurisdiction comes up with its own arbitrary regulations on requirements such as minimum spacing between sites, usually without taking into account currents and other environmental factors.

However, one of the ways in which research has directly affected the management process is through the work of Dave Greenberg and Fred Page on the definition of Bay Management Areas (BMAs). By the use of physical circulation models they are able to calculate the extent to which effluents from one site are dispersed into other sites, and thus the degree of interaction between farms in different areas. This work has the potential to provide a solid basis for determining farm separation and regional holding capacity. Carried out in tandem with epidemiological studies the approach could be of great value in formulating regional policies for aquaculture management. Still, there is a great deal of work yet to be done in this area – the present models use only a constant M2 tidal component and do not take into account the stronger but less frequent effects of spring tides and storm events, and the work has so far been applied to just one area.

This research points to a different type of basic problem which deals with the physical modelling of currents and flushing. Dave Greenberg presented some impressive modelling results for the Quoddy region and showed that the methodology could deal with some general problems of determining the circulation in difficult tidal areas (in particular the vexing problem of describing intertidal zones), but during discussion of the challenge of extending the methodology to new areas the ease with which new models could be produced was not clear – Greenberg and Fred Page came up with an estimate of one or two years to develop a new model, but this is the kind of issue that needs to be clearly resolved if these models are to be incorporated into policies for managing aquaculture and other uses of the coastal zone. It is important to distinguish between applied research that can be carried out only by world-class scientists and that which can be contracted out on a production basis as needed – to use an analogy from auto racing, we don't have so many Jacques Villeneuves that we can assign them to driving busses. Many of the scientists who worked on the ESSA project are not only the best in their fields in Canada, but they are among the best in the world, and if the analyses that they did are to be carried out on a regular basis as part of a uniform management policy, their work will have to be codified and reduced to technical routines.

Another topic which received little attention and is perhaps not seen as a pressing concern is the rate of recovery of abandoned sites and the question of whether some of the impacts of aquaculture might be irreversible. This requires long-term studies which are not feasible in the time frame of a 3-year project like ESSA, but the presentation by Gerhard Pohle and Dave Wildish showed that by combining current studies with historical data it is possible to obtain at least tentative answers.

Several talks dealt with sedimentology, and it is clear that considerably more work needs to be carried out in this area. Ironically it seems that the more we learn, the more we find needs investigation. There was a consensus that much of the instrumentation on which past studies have relied, such as sediment traps and the

Benthic Organic Seston Sampler (BOSS), are of limited value, especially in the relatively shallow water where many fish farms are located. As in many other fields of oceanography, the importance of episodic events is becoming more appreciated, and clearly these are extremely significant for benthic sediments with a threshold current speed for resuspension.

The problems of identifying depositional areas and deciding where the material in them originates were also unresolved. Various tracers associated with fish feed, such as Zn, Cu and P, were discussed, but this work can only be seen as preliminary. It could be useful not only to determine how much benthic carbon comes from fish feed but also to identify the individual farms responsible – this could easily be done with introduced tracers, but doing so is probably politically impossible, and the subject was not raised during the Symposium.

Comparative Studies

During his introductory comments, Barry Hargrave pointed out that BIO has had a long and successful experience with comparative studies of different ecosystems, but this element seemed to be missing from the work presented at the Symposium. Although I have been led to understand that some comparative analysis is under way, the absence of comparative studies is unfortunate, given the scope of ESSA.

Part of the reason for this is presumably the difficulty and expense of travelling between study sites, but as the joint Canada-Norway workshop in the early 1990's showed (published in Fisken og Havet 13:61-68), even just comparing results after the research has been done can bring valuable insights. Perhaps a further symposium focusing on comparative results, presumably after the remaining analyses are complete, could address this matter.

A more serious obstacle to carrying out comparative studies however is the uneven distribution of scientific expertise across the country. While the excellent work on nutrients and phytoplankton described at the symposium were of enormous value, it is a pity that these studies were only carried out in the relatively well-flushed Bay of Fundy and not in areas where nutrient enrichment is more likely to be a problem.

Access to information on current levels of stocking and production is another issue that came up repeatedly during the Symposium, and although the situation seems to be improving, some of the studies were adversely affected by having to work with data from sites that were not fully identified because of concerns about the confidentiality of commercial data. This means that researchers wishing to explore alternate hypotheses about relevant processes do not have access to such basic site-dependent data as current profiles and bathymetry. It is difficult to carry out comparative studies of different regions when it is not even possible to carry out comparative studies of different sites. A related problem is that feed composition is always changing, and researchers do not generally know what is currently in use. This makes it very difficult to develop models of effluent fate since without knowing precisely what goes into the fish it is hard to estimate what comes out. Peter Strain pointed out that not even the individual Feed Conversion Ratios (FCR) were available

to him, just the regional average, and it is difficult to see how current research on nutrient budgets can proceed any further under such constraints.

Given these problems, it is remarkable how much work could be done on nutrient dynamics and the impact of aquaculture on microbial and algal communities. Given that the study area for most of the work is well-flushed, and primary production tends to be light-limited rather than nutrient-limited, the ability of researchers at BIO and St. Andrews to carry out their work is inspiring. These investigations need to be carried out in other regions as well – it is clear that we have the expertise to understand the fate of nutrients, but we do not yet have the data to apply this expertise in all areas where it is needed.

Part of the reason for the lack of comparative studies is that the structure of ESSA seems to reflect an *ad hoc* approach to research planning which may not always be the most effective way to design a large-scale program. While this is understandable given the limited resources available and the necessity to focus research in areas where staff and equipment are available, a more coherent program might prove more effective. Research planning within DFO tends to reflect a mixture of top-down and bottom-up control, where initially a sum of money is made available for projects which are described in general terms, and then individual research groups submit proposals to carry out part of the work. There is a lack of middle management involvement to coordinate the individual projects so as to attain goals that might be beyond the reach of separate groups. In particular, as each project is developed there should be a mechanism for judging whether the project should be carried out at several study sites, or whether a single site is sufficient.

Monitoring Issues

Monitoring is a critical part of aquaculture management, and effective monitoring requires protocols that are both accurate and cost-effective. Several measures have been investigated, such as ammonia and sulphate gradients and redox potentials, but no clear consensus emerged from the Symposium on how best to measure benthic impacts. The paper by Robin Anderson, Vern Pepper and Michael Tlusty suggested that the patterns observed in the Bay of Fundy do not apply as well in Newfoundland waters. Most of the criteria currently in use or proposed are geochemical, although Dario Stucchi and Terri Sutherland referred to an Infaunal Trophic Index which shows correlation with Benthic Carbon Loading, and Cappitellid concentration has been used as an indicator in SW New Brunswick. This is an area that needs more investigation, since without reliable indices of benthic impact it is difficult to develop a credible monitoring strategy.

Although the intent of ESSA was to investigate the long-range impacts of aquaculture, many of the talks dealt with near-field effects, such as the study of oxygen levels within pens by Fred Page and Peter Strain. This work is certainly important, but the shift to near-field studies reflects the difficulty of maintaining a focus on research which deals with widespread secondary effects rather than localised dramatic impacts. Two factors contribute to this – the emphasis on applied research, since the value of near-field studies is more immediately evident than the investigation of long-range

effects which may not show up for a long time, and the need for industry co-operation, which clearly is motivated more highly by research that can improve husbandry practices than by more diffuse studies of matters that are mostly relevant to other stakeholders.

As Barry Hargrave pointed out in his opening remarks, the work in ESSA has proceeded from the relatively straightforward tracking of pollutants to the much more difficult task of determining their impacts. This is an important challenge, especially in the far field where the impacts are smaller, but affect larger areas and are more likely to interfere with other uses of the coastal zone. It is important that this work carry on.

There was little discussion of Integrated Coastal Zone Management (ICZM) during the Symposium, and Karen Coombs during the discussion of her paper observed that although there is consultation with other coastal zone committees, there is as yet no formal structure for ICZM in New Brunswick. A similar discussion at the end of Mark Cusak's talk indicated that the same was true on the national scene. This situation seems a bit paradoxical in light of the emphasis on long-range effects in ESSA, since from an aquaculture perspective it is the short-range effects that are most important, and long-range effects are the ones most relevant to other types of coastal zone use (which is not to ignore the impacts on other fish farms of course). Incorporation of aquaculture regulation into ICZM has long been discussed, and should probably be addressed in the near future. However, as Cusak pointed out, "Bureaucrats tend to address urgent rather than important issues", and while there is an active aquaculture industry out there to be dealt with, there is no pressing push for ICZM.

Decision Support Systems

Two papers discussed the development of Decision Support Systems (DSS), which are expert systems designed to make scientific expertise available to decision-makers even when the scientific experts themselves are not available. Both paper presenters reported substantial interest on the part of managers and stakeholders. While this is a very promising development and shows that the time is ripe for looking at means to deliver the knowledge accumulated during the ESSA project, there is also a negative aspect, in that it appears that DSS development is not proceeding in a logical fashion and may lead to false expectations that will eventually lead to rejection of this approach.

The paper by Barry Hargrave presented an attractive user interface for entering relevant data and presenting results. However the inner workings of the DSS are very crude and it is likely to produce unreliable results. Each value entered is evaluated separately and scored independently of other data, which is not what a human expert would do. For example, we know that dispersion of particulates over the seabed depends both on the depth and the current speed, and there is a trade-off between the two values – a current speed that would be inadequate in shallow water may be sufficient to produce a large and thus diluted footprint in a deep fjord. A simple model would compute the size of the footprint by looking at the product of depth times current speed, but no models are included in the sample DSS which was presented.

The lack of models in the DSS would not be a problem if there were a project under way to add this modelling capability and other forms of scientific expertise to the existing version, but apparently it is not under active development and there is pressure to use the current version in its present form. I think that this is unwise – a DSS is an expert system and should incorporate true expertise, and not just be an automated checklist for evaluating the entry data.

The presentation by Fred Page, Rob Stephenson and Blythe Chang included much more scientific content, particularly the use of a Geographical Information System (GIS) in the decision-making process, although it seemed to be more a system to bring together information for scientists to use than a tool for delivering scientific expertise to other concerned parties. Certainly the method they describe provides valuable information to stakeholders, but in the version shown at the Symposium the process still seemed to be one of scientists using the tools and then explaining them to clients, rather than having a package that farmers and managers can use on their own. There should in any case be little doubt by now that GIS can play a major role in Integrated Coastal Zone Management, and a DSS should include linkage to GIS as an essential process of the evaluation process.

Between the two presentations one could see the basic substance of a DSS emerging, combining the elegant interface that Barry Hargrave has developed with the GIS and other scientific content of the St. Andrews group. A DSS in order to be a true expert system needs to include an ability to do some modelling using the input data, but this is straightforward and has already been implemented by several groups. More consideration needs to be devoted to presenting the results in the most transparent and informative way possible, and perhaps the work that has been done in the Marine Fish Division to extend the simple traffic light methodology that Barry Hargrave used (red, green and yellow flags to categorise the ranges of the various variables, with blocks of mixed colours to represent borderline cases) could be incorporated. There is a great deal of potential in this approach, but if it is developed in a helter-skelter manner and released for use prematurely the reaction could be very negative.

Summary

Some aspects of needed research were conspicuous by their absence in ESSA. Gilles Olivier, in addition to identifying disease transmission as an issue of concern, raised the point that there is little certainty in our ability to predict aquaculture impacts, and we should be trying to develop strategies for managing risk. There is growing awareness in the fisheries area of the role that risk can and should play in management, and clearly this could be taken into account in future work. For example, the output of an epidemiological model may be a probability of disease transmission as a function of stocking density, rather than a clear threshold value. Similarly one can speak of a risk of anoxia rather than a firm prediction, especially given the uncertainties in feed composition, FCR, and other critical variables.

The issue of communication between science and industry came up frequently during the Symposium, both because of the problems that scientists have had in obtaining proprietary data and in planning research that meets the needs of the industry. While

Nell Halse and Jamey Smith spoke in terms of mutual trust and development of confidence, there were few concrete suggestions for how to build up this confidence. The general view seemed to be that there needed to be more face-to-face meetings, although with the workload of fish farmers and the travel constraints of government scientists these might be difficult to arrange as frequently as desired. One suggestion was for a Science-Industry Forum to meet every month or so, modelled along the lines of other programs that have proved successful with the fishing industry.

Overall the Symposium was a valuable and successful wrap-up to a major project which will be of great value both to DFO and to the global aquaculture community. The decision to publish the proceedings is a wise one and should be publicised not only within Canada but internationally as well, through the relevant ICES committees for example. However, the job is not over, and more work needs to be done. There is an ongoing need for more basic research in this field, and it is likely that stakeholders outside the aquaculture industry will push for more research on long-range and long-term effects. Comparative studies are needed if ESSA is to provide a basis for aquaculture planning in Canada (and elsewhere) rather than providing a model for work that has to be repeated for every new site. And as our scientific knowledge grows, more effort has to be directed at ensuring that all our hard-earned expertise is made available to the stakeholder community, including managers, industry, and the general public. This is a big job, but the Symposium got it off to a good start.

Science Management Perspectives on the ESSA Project

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One of the major goals of the Environmental Science Strategic Research Fund (ESSRF) was to ensure that scientific research that was funded was directly linked to operational objectives. It is therefore important and relevant to consider the results of the ESSRF funded "Environmental Science for Sustainable Aquaculture" from a management perspective. Is there advice for Habitat or Oceans Management, the Office of Sustainable Aquaculture, the Regional Aquaculture Co-ordination Office or the DFO – NB and DFO – NS Aquaculture MOU Committees?

While the principle focus of the ESSA project was the detection of far-field impacts our knowledge of near-field impacts was also enhanced. Here is a list of the management-relevant information that was presented at the workshop, first of all for the near-field:

- Large changes occur in the sediment chemistry and biology directly under sites where organic wastes accumulate. Also oxygen concentrations can be depressed at some times at some sites.
- Contaminants are accumulating in these sediments. The major source of both organic contaminants and the trace metal Zn is the fish food.
- The metal Cu is also accumulating around cage sites. The major source of this contaminant is anti-fouling coatings on nets and other equipment.
- The levels of Zn in sediments around some cages exceed the level at which there is a probability of biological affects on marine organisms.
- The levels of some organic contaminants in the fish feed is at levels of biological concern.
- The deposition of wastes at a cage site can be modelled with reasonable accuracy provided some basic information about the physical oceanography and operating practices of the site are known. These models can be used to optimize site design and monitoring program design.
- The indicators used for the New Brunswick Environmental Monitoring program are not universally applicable. Indicators and associated reference points have to be selected and validated for different environments.
- While poor environmental health, in itself, will not result in an increased incidence of fish disease, it is a contributing factor.

Far-field effects:

- There is no strong evidence for major environmental changes on an area-wide basis that can be attributed to aquaculture development. However, in some areas of intense aquaculture, e.g. Lime Kiln Bay, NB, there are bay-wide changes that may be the result of aquaculture activity.
- Some bays, such as Lime Kiln Bay, show widespread impacts due to the intensity of the development.
- Aquaculture operations have resulted in more fine grain sediments remaining in the area. This may be having an overall impact on benthic communities but it is not readily demonstrated.
- There are demonstrable and major changes in the benthic community in some study areas distant from aquaculture sites. While a definitive cause and effect relationship cannot be established, aquaculture wastes are likely a contributing factor.
- In SWNB the aquaculture industry has the greatest impact on marine environmental quality.
- Antibiotic resistant bacteria are found throughout the area as a result of aquaculture operations. The bacteria have likely been introduced in the fish feed. The significance of the resistance is unknown.
- The finite element hydrodynamic model would be a useful tool for optimizing site locations in the area.

Some outstanding research questions:

- A large amount of the waste nitrogen from the farms is unaccounted for. What is its fate?
- Is the fouling community associated with cage sites of significance in the processing of aquaculture wastes or in controlling oxygen concentrations?
- There has been a change in the phytoplankton community structure. Has this been influenced by the increased nutrient availability?
- Phosphorus may be a useful indicator for tracing and monitoring aquaculture wastes. More information is needed about its source, fate and distribution.
- Can the use of trace metals or P as indicators improve the accuracy or efficiency of the EMP?
- The impact of aquaculture wastes on intertidal areas within the Bay is still unresolved.
- There is a need to identify indicators and associated reference points for non-depositional environments.
- Operational information for sites is required to advance our understanding of area-wide impacts and the correlation between fish health and environmental health.
- Chemicals used for parasite control need to be carefully evaluated for their potential impact on non-target organisms.
- Decision Support Systems (DSS) are an efficient way for delivering science information and tools to management. Future work should investigate the usefulness of a GIS interface to acquire data and models to further enhance the assessment. A DSS needs to incorporate regional or area-specific indicators and reference points.

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APPENDIX A

SYMPOSIUM PROGRAM

ENVIRONMENTAL STUDIES FOR SUSTAIABLE AQUACULTURE (ESSA) SYMPOSIUM
27-29 January, 2004

Bedford Institute of Oceanography, Main Auditorium

(*extended abstract not available)

Tuesday, January 27, 2004

Introduction (B. Hargrave)
Welcome (M. Sinclair, RD Science, Maritimes Region)

ESSA overview and final report (B. Hargrave)

Application of a high resolution circulation model to aquaculture issues in the Quoddy Region (D. Greenberg)

Deposition models as predictive tools for assessing aquaculture impacts (D. Stucchi, T. Sutherland, C. Levings)

Radionuclide geochronologies for aquaculture contaminants in sediment cores from Lime Kiln Bay (J.N. Smith, P. Yeats and T. Milligan)

The effect of aquaculture on fine grained sediment dynamics in coastal embayments (T. Milligan and B. Law)

Zinc in sediments as a tracer of farm wastes (P. Yeats, T. Milligan, T. Sutherland, J.N. Smith, S. Robinson, P. Lawton and J. Smith)

Apportioning sources to PAH PCB and DDE detected in sediments around aquaculture cages (J. Hellou, S. Steller, K. Haya, C. Chou and L. Burridge)

A regression model using sediment chemistry for the evaluation of marine environmental impacts associated with salmon aquaculture cage wastes (C. Chou)

Chemicals to control sea ice infestations: What we know about their effects on lobster (L. Burridge)

Microbial resistance to oxytetracycline in sediments from salmon aquaculture sites in the Western Isles region of the Bay of Fundy (S. Armstrong, F. Friars, B. Hargrave and K. Haya)

Wednesday, January 28, 2004

**Overview/discussion of first day's presentations* (P. Keizer)

Phytoplankton and harmful algal blooms (HABs) in the Bay of Fundy (J.L. Martin and M. LeGresley)

Ecosystem indicators of water quality I: Plankton biomass, primary production and nutrient demand (G. Harrison)

Ecosystem indicators of water quality II: Oxygen production and oxygen demand (P. Kepkay)

Salmon aquaculture and dissolved oxygen levels in SWNB (F. Page and P. Strain)*

Salmon aquaculture, nutrient fluxes and ecosystem processes in southwestern New Brunswick (P. Strain and B. Hargrave)

Impacts of eutrophication on the intertidal zone in temperate areas with emphasis on the soft-shell clam, mya arenariai (S. Robinson, L. Auffrey, M. Barbeau, and P. Yeats)

Downstream water quality impacts of net-cage facilities on shellfish (S. Cross)

Organic enrichment at cold water aquaculture sites – the case of coastal Newfoundland (M.R. Anderson, V. Pepper and M. Tlusty)

Benthic macrofaunal changes in the Letang Inlet: a quarter century view of an industrialized area (G. Pohle and D. Wildish)

**Spatial trends in meiofaunal assemblages in relation to fish farm operations* (T. Sutherland and C. Levings)

Thursday, January 29, 2004

Industry perspectives on sustainable operation and development of marine salmon aquaculture (N. Halse and J. Smith)

Environmental management and regulation for sustainable finfish aquaculture development in New Brunswick (K. Coombs and D. Joy)

DFO Aquaculture Co-ordination Office at BIO (M. Cusak)

A decision support system for evaluating new farm site applications (B. Hargrave)

**A decision support framework for coastal zone management* (F. Page, R. Stephenson and C. Chang)

Changes in the environment due to the salmon aquaculture industry, do they pose an increased risk of disease incidences? (G. Olivier)

General discussion on future research needs for environment-finfish aquaculture science, fish-health and environment interactions, objective-based management, decision support system, offshore development

APPENDIX B

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